UNIVERSITY OF CENTRAL FLORIDA (UCF)
DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

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INVESTIGATION OF A WHEELCHAIR GAS GENERATOR SYSTEM

August 1992

Prepared for: **TECHNOLOGY AND ADVANCED PROJECTS OFFICE**

Prepared by: Dr. Loren A. Anderson, Associate Professor, UCF
Mr. Otto H. Fedor, Adjunct Professor, UCF

Assisted by: Wyatt J. Englehart, UCF
Duane A. Grant, UCF
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John F. Kennedy Space Center
Kennedy Space Center, Florida 32899
NASA Grant NAG-10-0096

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Investigation of a Wheelchair Gas Generator System

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Novmeber 25, 1992

NASA Scientific and Technical Facility
P.O. Box 8757
Baltimore/Washington International
Airport, Maryland 21240

Subject: Grant No. NAG 10-0096, Wheelchair Gas Generator System

Dear Sirs:

In accordance with Article 7 of the Federal Demonstration Project General Terms and Conditions, attached is one reproducible copy

EXECUTIVE SUMMARY

NAG 10-0096 Study Grant was issued to the University of Central Florida (UCF), Department of Mechanical and Aerospace Engineering to investigate the design of a regenerative solid propellant gas generator power system as a follow-on to the feasibility study (NAS 10-11143).

The gas generator power system uses high pressure gas to recharge a hydraulic accumulator that provides energy to a hydraulic motor. This system was chosen primarily because of the following inherent advantages over other systems:

* Low heat source
* Nonsparking motor
* Thermodynamics
* Hydraulics

Because of these advantages, this power system has the potential for numerous commercial and military applications. The application of an alternative power source for wheelchairs is the basis for this design. Other applications include:

* Vehicles that come in contact with explosive gases
  - Rapid intervention vehicles
  - Mine rescue vehicles
* Easy adaptation of
  - Tools
  - Manipulators
* NASA
  - Space station applications
  - Planetary surface vehicles
  - Runway and launch pad rescue vehicle
* Underwater applications

This report discusses the significant development, testing, and investment of KSC and UCF on the evolution of the gas generator system utilized to power this hydraulic system. The design of the following seven components that compose the gas generator system is discussed in detail:

1. Firing Mechanism
2. Solid Fuel Cartridges
3. Gas Generator Body
4. Filter
5. Pressure Regulator
6. Intensifier
7. Muffler Heat Exchanger

Both the component tests and the system tests have been completed. Evaluation shows that 32 grams of Sodium Azide - Cupric Oxide in a power cartridge will produce 116 cubic inches of nitrogen gas at 83 degrees Fahrenheit and a pressure of 110 pounds per square inch (psi). A gas input of 75 psi

at a flow rate of 14 standard cubic feet per minute (scfm) takes 15 seconds for the intensifier used in this application to recharge a one-gallon accumulator from 500 psi to 2,500 psi.

The hydraulic motor, manufactured by Webster, will deliver one horsepower in the range of 500 to 2,500 psi hydraulic intake pressure. This equates to approximately 955 grams of sodium azide - copper oxide required for recharging the accumulator. It is important to note that the energy density and chemical formulation of the compound that was tested produces these results. Slight changes in grain size and percentage of each basic element sill significantly effect the compound's reaction.

A low efficiency solid propellant cartridge was chosen in the tests performed because it was readily available, stable, safe, had known properties, and produced 100 percent nitrogen.

It was suspected that this propellent combination would not produce sufficient gas to repressurize the one-gallon accumulator. However, the objective of this program was to prove that the concept would work. The concept was proven and engineering data was acquired necessary for design optimization decisions. Tests revealed that a supply of gas at 14 scfm for 15 seconds was necessary to regenerate a one-gallon accumulator.

Investigation and testing of a wide range of suitable propellants, both domestically and internationally, that will produce 14 scfm in a reasonable sized cartridge. One of the significant design features of the gas generator system is a heat exchanger/muffler that has scrubber ability and allows for the safe use of high energy propellants

A Work Breakdown Structure Report (Appendix C) and a Specifying Goals Report (Appendix D) have been developed to specify the subsystem performance requirements and operational constraints for the gas generator system prototype. This effort allowed the student design team to comprehend the tasks to be preformed and provided a structured approach to the project.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF ACRONYMS AND ABBREVIATIONS

°F	degrees Fahrenheit
NASA	National Aeronautics and Space Administration
NPT	National Pipe Thread
KSC	John F. Kennedy Space Center
UCF	University of Central Florida
psi	pounds per square inch
scfm	standard cubic feet per minute

TABLE OF CONTENTS

APPENDIX A - FIGURES

TABLE OF CONTENTS

APPENDIX B - TABLES

Investigation of a Wheelchair Gas Generator System

INTRODUCTION

In 1982, Mr. Otto Fedor of Kennedy Space Center wrote a working paper entitled "Advanced Concepts in Development of a Powered Mobility System." [1] Since that time, the University of Central Florida and Kennedy Space Center have taken an active role in a joint effort to develop an alternate power source and to optimize that alternative in order to provide an advanced 21st century wheelchair design.

The Americans With Disabilities Act recently passed by the U.S. Congress emphasizes the need for NASA to fulfill its commitment to the transfer of technology gained in space exploration to benefit the handicapped in the civilian sector. There is much encouragement to continue the development of an innovative powered mobility system by a grant from NASA-KSC Technology and Advanced Projects Office.

A design team was formed under the direction of Mr. Otto Fedor to explore the aspects of the gas generator system. This team was composed of students in the Fall-1991 and Spring-1992 Senior Mechanical and Aerospace Engineering design classes at the University of Central Florida, Orlando. Fabrication and testing of the developed system were accomplished during this period.

The purpose of this report is to present the issues associated with the component design of the gas generator system and the results of the investigation. This system will supply energy to the chosen alternative power source. The development of the gas generator system is the third of a four phase NASA plan to produce a working power system. The power system is described in a 1983 report to the National Aeronautics and Space Administration, entitled "Alternate Power Sources for Wheelchairs" by Dr. Loren A. Anderson and Mr. Rod Henry, University of Central Florida. [2]

The first phase of this plan was completed to prove in principle the concept of a depletion cycle engine. The design and production of this system allow the pursuit of a final product that will improve the quality of life for those employing or confined to wheelchairs. This is achieved by providing an improved means of wheelchair transportation.

The second phase of the project, consisting of research performed by Dr. Anderson and Mr. Henry of the University of Central Florida, shows that this product is practical. The Veteran's Administration, [3] rehabilitation centers, and the Institute of Handicapped Research [4, 5] have been contacted and response shows an established need for this product. This research also shows that a technological advancement by producing a new design wheelchair has a very high probability of acceptance among the handicapped and the public, [6,7] especially in the new environment created by the "Americans With Disabilities Act."

Investigating and solving the design concerns of the gas generator system provide a benefit that enhances the quality of life for those less fortunate. The design and production of this system allow the pursuit of a final product that will improve the quality of life for those employing or confined to wheelchairs. This is achieved by providing an improved means of wheelchair transportation.

Persons confined to wheelchairs will receive many benefits from the development of the gas generator system. It will allow users to have an unlimited range and provide a power seat lift that will assist in physiological effects and kidney functions. It also provides stair-climbing capability. Battery powered wheelchairs, even if a charger and power source are available, require a substantial recharging period (several hours). [6,7] The gas generator system does not require any recharge time.

The powered wheelchair configuration is depicted in Figure 1 of Appendix A. The stair-climbing capability mentioned above is shown in Figure 2 of Appendix A. This mechanism is described in a NASA Tech. Briefs entitled "Articulated Suspension Without Springs" published in January of 1990. [8]

Options for the size and shape of the solid fuel cartridges, filter, intensifier, and muffler heat exchanger are discussed in this report. Previous engineering calculations and design groups have optimized the design of these components. [9]

TECHNICAL EVALUATION

The scope of this system consists of a series of design tasks associated with the individual components of the gas generator system. A schematic showing the gas generator system layout is shown in Figure 3 of Appendix A. The power unit consists of a hydraulic motor driven by a pressurized hydraulic pneumatic accumulator. The accumulator is recharged by a hydraulic intensifier. The intensifier is driven by a benign solid propellant gas generator that uses multiple cartridges for extended operational periods.

The complete hydraulic, drive, and gas generator systems must be able to be contained in a volume of 16 inches by 16 inches by 9 inches. This constraint is dictated by the ability of a wheelchair to fit through standard doorways. Appendix A, Figure 4 shows the location of the power unit in a standard wheelchair.

A report detailing the work breakdown structure [10] associated with construction of this system is attached to this report under Appendix C. The Work Breakdown Structure report establishes and presents the rudimentary outline and schedule for completing the component design, testing and presentation of a prototype gas generator system. A construction schedule with required completion dates and team personal responsibility are presented in this report.

The testing of this system met the requirements defined in the specifications developed for the gas generator system [11] as outlined in the "Specifying Goals Report" (Appendix D).

A total of ten tests was required to evaluate the performance of the gas generator system. The details of test objectives, setups, procedures, results, observations, and recommendations are discussed in this report.

Knowledge of the principle duties of each component of the gas generator system allows for a better understanding of the test results. Those duties and the design issues associated with the development of the prototype gas generator are:

* Time required to recharge a one gallon accumulator from 250 psi to 2,500 psi with a 75 psi air intake to the intensifier.

* Determine the flow required from a solid fuel cartridge to recharge the one gallon accumulator.

* Power the hydraulic motor with varied flow rates at pressures from 250 psi to 2,500 psi.

The design options for each of the seven components are as follows:

1) **FIRING MECHANISM.**

The firing mechanism contains and ignites the solid fuel cartridges via a mechanical pneumatic signal. The firing mechanism contains an adequate amount of solid fuel for typical wheelchair use and is designed for easy replacement of the solid fuel cartridges.

The design requirements consist of the following:

* Reliability
* Maintainability
* Simplicity
* Durability
* Safety
* Size

Five options presented for the design of the firing mechanism include:

* Rotating Firing Mechanism Head.
* Rotating Firing Mechanism Chamber.
* Automatic Arrangement with Clip.
* Bolt Action.
* Pneumatic Pistons with Binary Valving.

*** Rotating Firing Mechanism Head.**

This design mechanism is depicted in Figure 5 of Appendix A. It incorporates the same type of ignition device as a typical revolver, such as a Smith and Wesson shown in Figure 6 of Appendix A, with the difference of a fixed barrel with a rotating firing hammer.

The rotating firing mechanism head system utilizes the same principle as a revolver with some exceptions. The major design change allows the cylinder to be stationary and the head to rotate and ignite a fuel cartridge simultaneously. The firing head rotates about the center of the cylinder from one cartridge to another. The movement of the head is activated by a signal. This signal is transmitted when the hydraulic pressure in the system falls below 1,000 psi.

The specific components of the rotating firing mechanism head design consist of a stationary cylinder, containing four cartridges with firing centers spaced at 90 degree increments. The diameter of this cylinder may be varied to accommodate multiple numbers and/or sizes of solid fuel cartridges. The bottom of the firing mechanism body converges to allow for the connection to the gas generator body. The top of the firing mechanism will use a locking or screw type configuration to allow for easy replacement of solid fuel cartridges.

The firing mechanism head is connected to the center of the firing mechanism body by a tensioned spring and latch. The firing mechanism is hydraulically rotated 90 degrees when ignition is needed. The rotation angle of 90 degrees may be varied when utilizing a number of solid fuel cartridges other than four. Ignition is performed by advancement of the hammer. As the hammer is elevated, spring tension increases.

The release of potential energy in the spring enables the hammer to ignite the solid fuel cartridge. The hammer stays in this position until the next ignition cycle.

The advantages of this design are the following:

* Simplicity
* Ease of Operation
* Enclosed System
* Ability to Vary Size

*** Rotating Firing Mechanism Chamber.**

This model, as depicted in Figure 7 of Appendix A, incorporates the type of firing mechanism of a typical revolver. An example is a Smith and Wesson revolver [12] with a rotating barrel and stationary firing hammer as shown in Figure 6 of Appendix A.

The rotating chamber design is similar to a revolver due to the rotating barrel and a stationary firing mechanism. The firing mechanism rotates and ignites the solid fuel cartridges in one motion. The rotation of the chamber is activated by a signal sent from a pressure sensor. This sensor is activated by a decrease in system pressure below 1,000 psi.

Specific components of the rotating firing mechanism chamber design include a firing mechanism body. This body contains four cartridges with centers spaced at 90 degree increments. The chamber rotates 90 degrees per signal and is similar to a rotating firing mechanism head system. The diameter of the cylinder may be varied in accordance with solid fuel cartridge requirements. The discharge end of the firing mechanism body converges to allow for the connection to the gas generator body. The head of this design also utilizes a lock mechanism to allow for the removal and replacement of the solid fuel cartridges.

A stationary ignition mechanism is connected to the center of the firing mechanism body by a tensioned spring and latch. Ignition is performed by the use of a wedge shaped attachment located on the inner diameter of the firing mechanism body. As the ignition device approaches the edge of the elevated section of the wedge, the spring increases in tension. When released, the ignition mechanism strikes and ignites the solid fuel.

Advantages of this design are as follows:

* Enclosed System
* Ease of Operation
* Ability to Vary Size

A disadvantage of this design is its complexity.

*** Automatic Arrangement with Clip.**

This design, as depicted in Figure 8 of Appendix A, allows for a clip type apparatus to load the solid fuel cartridges into the firing chamber. A firing pin ignites the solid fuel cartridges. This mechanism is similar to the Smith and Wesson model 59 [13] shown in Figure 9 of Appendix A.

The automatic arrangement with a clip system functions according to the following four steps:

1. A removable clip allows the solid fuel cartridges to be loaded into the firing mechanism.

2. A hydraulic piston is activated by way of a signal transmitted when less than 1,000 psi system pressure is detected.

3. The hydraulic piston is actuated, allowing the fired solid fuel cartridge to be expelled.

4. The next fuel cartridge is placed into the chamber by the piston and ignited. The piston stays in this position until the next ignition cycle.

Some advantages of the automatic arrangement with a clip design are that it is simple and can utilize multiple solid fuel cartridges. An obstacle of applying this design to the gas generator system is its size.

*** Bolt Action.**

This model, shown in Figure 10 of Appendix A, utilizes a single cartridge that is manually loaded. This design is very simple in that it resembles most bolt action rifles. An example of this type of arrangement is the Mauser Kar 98k shown in Figure 11 of Appendix A.

The bolt action rifle arrangement system utilizes the procedure in the following four step cycle:

1. A removable clip acts as the reservoir for the solid fuel cartridges to be loaded into the firing mechanism.

2. A pressure sensing device provides a signal to the firing mechanism when more fuel is required.

3. A lever is manually unlocked and removed. A spring in the clip causes a new fuel cartridge to be loaded into the firing chamber.

4. A lever is placed in position and locked. A manually operated triggering device ignites the solid fuel cartridge. A relief valve is supplied to avoid overcharging.

The advantage of the bolt action rifle design is its simplicity. The disadvantages of this design are that it is not automatic, and the area needed to physically change a cartridge is limited.

*** Pneumatic Pistons with Binary Valving.**

Appendix A, Figure 11 depicts the layout of this firing mechanism. The top of the firing mechanism will use a safety locking device to allow for easy replacement of solid fuel cartridges and prohibit the system from igniting a cartridge when not securely in place.

Ignition is performed when accumulator pressure diminishes to 500 psi. A pressure sensor feeds a signal to a solenoid valve which supplies gas pressure to a percussion actuator.

The actuators are operated in sequence by a parallel and series combination of binary valves (directional control valves). Appendix A, Figure 12 shows the operation of these valves. Gas pressure is alternated sequentially between two exit ports. Tests one, three, and four of this report are used to evaluate the operation and performance of the firing mechanism system.

2) <u>SOLID FUEL CARTRIDGES.</u>

The purpose of the solid fuel is to provide gas to the intensifier. These cartridges must be designed for easy removal and installation, available from multiple suppliers, and safe during long periods of storage. They must also have a safe discharge into the environment.

The size of the cartridges is important due to system charging requirements. Depending upon the final tested system's requirements, the number and size of fuel cartridges may vary.

Five possible fuels able to be utilized in the design of this system consist of:

1. Hydrazine
2. Rubber Ammonium Nitrate
3. Sodium Azide - Copper Oxide (slow-burning)
4. Compressed Air
5. Sodium Azide - Copper Oxide (fast-burning)

The differences in the fast-burning versus slow-burning sodium azide - copper oxide are due to the cold compressing process during the formation of the chemical. [14]

*** Rubber Ammonium Nitrate**

Rubber ammonium nitrate is an intermediate energy, nontoxic based compound which emits about 3.6 percent carbon monoxide. [7] This fuel contains an oxidizer for complete combustion, releasing close to 750 watt hours per pound. [6] A negative aspect of utilizing this chemical in an application of a wheelchair design is during indoor operation in an unventilated room. Hydrocarbons released by combustion of the rubber ammonium nitrate are considered as carcinogens in this type of application. [6]

*** Sodium Azide - Copper Oxide**

Sodium azide - copper oxide, fast or slow-burning, is a low energy, nontoxic based compound which emits nitrogen gas, therefore not harmful to the environment. Although this fuel releases less energy, 189 watt hours per pound compared to rubber ammonium nitrate, [6] it does not release harmful hydrocarbons. The advantage of using a slow-burning fuel is that it provides a better source of a steady flow and eliminates the need of an accumulator. An accumulator would be needed to store the energy released in a fast-burning fuel. A fast-burning compound of sodium azide - copper oxide would completely burn in about 0.25 seconds, [14] whereas the slow-burning compound would require about 45 seconds to completely burn.

*** Hydrazine**

Hydrazine is utilized as a source of power for actuators and motors on the Space Shuttle program. This fuel operates at 60 percent efficiency as compared to rubber ammonium nitrate and sodium azide - copper oxide systems which operated about 48 percent efficiency. [7] Considering fuel consumption for a ten (10) horse power system, hydrazine uses approximately 58 percent more fuel than the rubber ammonium nitrate and about 40 percent less than the sodium azide -

copper oxide. Sodium azide - copper oxide has a weight disadvantage compared to hydrazine. The hindrance of hydrazine is its corrosive and toxic properties. [7]

The propellant tested was a slow-burning version of sodium azide - copper oxide. The fuel is made of a cold-compressed slow-burning oxide compound. This corresponds to Talley Industries' propellant known as TAL-1101M [14] for which the propellant properties are shown in Appendix B, Table 1 and Appendix B, Table 2. The cartridges tested were 1.0 inch in diameter and 2.0 inches long. This amount of compound contained in each cartridge is approximately 32 grams. These cartridges were supplied by Stresau Laboratory, Inc., located in Spooner, WI.

Ignition is initiated by a primer located in a hole positioned at the center of the cartridge. A single cartridge, as shown in Appendix A, Figure 13, burns from the center of the cartridge towards the outside of the cylinder. This enables nitrogen gas, which is the product of this propellant, to expel through the hole into the gas generator body.

The results of tests two, five, six, and seven were used to determine system charging requirements and thus the size and configuration of the propellant cartridges. The final configuration of a sodium azide - copper oxide cartridge required to supply the intensifier has a chamber diameter of 1.735 inches and a length of 2.626 inches.

3) GAS GENERATOR BODY.

The function of the gas generator body is to capture the gas produced from the ignited solid fuel cartridges and direct the gas flow into the filter. The gas generator body is positioned between the firing mechanism and the filter as shown in Figure 3 of Appendix A.

The most important design features of the gas generator body that must be considered include:

* Pressure Drop
* Space Requirements
* System Adaptability
* Connectability to the firing mechanism and filter
* Ability to resist impingement from the ignited solid fuel cartridges

Seven distinct shapes and six materials have been suggested for use in the design of the gas generator body:

SHAPES

* Smooth Curve
* Straight
* 45° Bend
* Concentric
* Curved Nozzle
* 90° Nozzle
* Right Angle

MATERIALS

* Mild rolled steel A-36
* Stainless-steel; Type 304
* Nylon 6/6
* 0.3 percent Carbon Steel
* Aluminum 6061 T-6
* UHMW Polyethylene

Each of the suggested shapes and materials is commercially available.[15,16] Figure 14 of Appendix A depicts the seven suggested shapes.

The ignition of the solid fuel cartridges will include projectiles from by-products of the burning fuel.[14] The gas generator body will absorb these impingement loads. In the case of the straight and concentric shapes, most of these particles will pass through the gas generator body and be absorbed by the filter.

It is desirable to minimize the drop in pressure through the gas generator body due to the necessity to produce as much pressure as possible to the remaining system. Connection of the gas generator body to the firing mechanism and filter is a major concern. Flexibility in design due to the size and shape of the firing mechanism and filter must be considered. The gas generator body may be either welded (bonded if plastic or nylon) or threaded to provide a sealed connection.[17,18]

When a factor of safety of two is considered, seals connecting the gas generator body to the firing mechanism and the filter must meet a requirement of 6,000 psi or greater. This requirement must be met for all seals and connections for the entire power system. Table 3 of Appendix B shows the advantages and disadvantages of each shape.

Material selection for the gas generator body must consider properties that provide:

* Resistance to corrosion.
* Resistance to cyclic thermal fatigue due to ignition of the solid fuel cartridges.
* Ability to weld, bond, or fit (thread) the gas generator body to the firing mechanism and filter.
* Strength that will resist cracking and vibration fatigue.

Table 4 of Appendix B provides a summary of the material properties.[19,20,21] The advantages and disadvantages of these materials are shown in the Table 5 of Appendix B.

4) FILTER

The solid fuel combustion process releases nitrogen gas and particulate matter.[14] Because of the particulate matter, a filter is needed to clean the gas before it enters the intensifier. The head loss (pressure and flow decrease) and heat loss created by the filter were evaluated in tests five, six, seven, and nine.

The available types of filtering media that are considered for this system include:

* Cloth
* Paper
* Metal and Fiberglass Screen
* Ceramic and Porous Metals

Each filtering media has specific advantages and disadvantages, depending on the application.

Cloth filters are inexpensive and can withstand high temperatures and pressure. Screen type filters are mid-priced and provide high strength and temperature resistance. Although the filtration of screen filters is not as high as the cloth filters, the cloth filters do not hinder the fluid flow to the level of a cloth or porous type filter. Porous filters provide high filtration at the expense of flow obstruction. Porous filters are expensive but higher in strength and heat resistance.

The advantages and disadvantages of each are as follows:

* **Cloth Filters.**

  Cloth filters are cheap and eliminate particles larger than 0.5 microns. Cloth filters are strong and heat resistant when manufactured from fiberglass or Kevlar. This feature is important in application to the gas generator system because the entering gas is approximately 1,950 degrees Fahrenheit and 2,500 psi.

* **Paper Filters.**

  Paper filters are the cheapest of all filters and trap particles larger than 0.5 microns. The disadvantages of a paper filter are its low strength and heat resistance.

* **Metal and Fiberglass Screen Filters.**

  Metal and fiberglass screen filters are higher in strength and heat resistant than cloth or paper filters. These screen filters minimize flow obstruction; however, they do not clean a fluid as well as other filter media.

* **Porous Ceramic and Porous Metal Filters.**

  Porous ceramic and metal filters are more expensive and can filter out finer particles than other types of filters. Porous type filters are also higher in strength and heat resistance than other types of filters. The high strength and heat resistance stem from the fact that the filters are made from metals and ceramics. Despite inhibiting fluid flow, porous type filters have an advantage where high filtration requirements exist.

5) PRESSURE REGULATOR.

The intensifier works on an operating pressure of approximately 75 psi. Therefore, the gas pressure expelled by the fuel propellant must be regulated to meet this requirement. Test nine was generated specifically to evaluate the filter and regulator performance.

After the nitrogen gas exits the filter, the pressure is just below 3,000 psi. The intensifiers to be utilized require an input pressure of approximately 75 to 100 psi. Therefore, the pressure must be reduced from 3,000 psi to this input requirement between the filter and intensifier. Due to these requirements, size is an important factor in the component chosen.

Five designs have been suggested for utilization on flow and pressure regulation:

* Cavitating Venturi
* Sharp Edged Orifice
* Nozzle
* Flow Rate Controller
* Reducing Valve

A venturi, as shown in Figure 15 of Appendix A, produces a steady flow, but requires the most space of all five designs. This space requirement is a major concern for the reasons previously mentioned. A venturi is relatively expensive and produces a pressure drop less than other flow control devices.

A nozzle's performance is between that of a venturi and an orifice. It produces more of a pressure drop than the venturi and less than an orifice. The exiting flow is steadier than that of the orifice but not as controlled as a venturi. The size and cost of the nozzle are between that of the orifice and the venturi. Figure 16 of Appendix A shows a typical nozzle.

An orifice, as depicted in Figure 17 of Appendix A, is similar in shape to a flat washer. An orifice is the most simple of flow control devices. It is small, very inexpensive, and produces a large pressure drop. The pressure drop is more than that acquired from a nozzle or venturi, considering the space requirements. A disadvantage of the orifice is that it produces an unsteady flow. The ability of the orifice to produce such a large pressure drop in such a small space is an advantage, as is its cost.

A flow rate controller is fast acting, compact, and self contained. It automatically compensates for changes in input and exit pressures to maintain a preset flow within 1.5 percent of its setpoint. [22] Flow rates can be manually set and options exists for electronic or pneumatic input. Appendix E shows a typical flow rate controller.

Reducing valves, as depicted in Figure 18 of Appendix A, have historically been limited to either cast iron or bronze bodies. These valves are now available in steel and stainless-steel models. They operate with a setpoint determined by the user, which is activated by air pressure on a stainless-steel diaphragm. [22] Loading pressure keeps the valve open while the desired reduced pressure builds up under the diaphragm, and the valve begins to modulate and equilibrium is reached.

6) INTENSIFIER.

The intensifier is a simple pressurizing device. Gas enters the intensifier at a low pressure, and through the exchange of different sized pistons, exits the intensifier at a higher pressure. In the application of the gas generator system, nitrogen gas enters the intensifier at a pressure of 75 psi and is used to develop a working hydraulic pressure of approximately 3,000 psi. Tests two, five, and seven explore the performance of the intensifier.

7) MUFFLER HEAT EXCHANGER.

The muffler heat exchanger applied to the gas generator system is a unique design (Mr. Otto Fedor holds the U.S. patent). [23,24] Therefore, this design can be altered as required for this application.

The muffler heat exchanger of this system meets exhaust conditions of ambient pressure and less than 100 ^{o}F. The results of test seven are used to develop the input parameters of test eight which grade the performance of the muffler heat exchanger.

The muffler heat exchanger, as shown in Appendix A, Figure 19 operates by splitting its input flow into two paths. The flow from the two different paths is directed into each other, thus providing equilibrium in the flow's momentum and pressure forces. The cancellation of the flow forces provides an exit pressure equal to ambient conditions.

The muffler heat exchanger removes heat from the gas generator system by utilizing a counter flow heat exchanger in the design. The counter flow method is used to provide the largest temperature difference between two fluids, therefore yielding the highest obtainable heat transfer. Heat is removed from the exiting gas by utilizing the system's working hydraulic fluid.

TEST SETUP

All testing was conducted at the Marathon Industries or at the King Street Test Facility located in Winter Park, Florida. The design team has constructed a specialized test bench. The gas generator design team conducted all of the tests. All high pressure tests required the approval and supervision of a faculty member.

TESTS - GENERAL

The testing of the gas generator system answered many questions on how to create a complete and working prototype. Determination of size, configuration, and quantity of fuel affect the design of the remaining system due to gas volumes and pressures required throughout the entire system. Testing of the fuel dictates required strength and size of the firing mechanism. Filtering and flow control is dependent upon the fuel and firing mechanism design. All these parameters must adapt to each other to optimize the design. Testing of the system components confirms preliminary design analyses.

Testing of this system demonstrates the necessity of the accumulator shown in Appendix A, Figure 3 before entrance to the intensifier. This accumulator captures additional gas pressure (energy) not immediately used by the intensifier.

The goals of the test plan may be summarized as follows:

1. Investigate the gas dynamics of the solid fuel propellant gas generator system.

2. Determination of the size, configuration, and quantity of propellant needed.

3. Investigate filter and flow regulation performance.

4. Verify the design of the muffler heat exchanger.

5. Obtain engineering data from a fabricated unit and provide proof of principle.

Specific test objectives, test setups and procedures associated with each of the tests performed are discussed separately in the following sections. A summary of the tests performed is listed in Table 6 of Appendix B.

TEST 1

OBJECTIVE

Determine the optimum and minimum gas pressures to operate the actuator pistons.

SETUP

Construct a system as shown in Appendix A, Figure 20, Test Schematic #1, using components as called for in the bill of materials for Test 1 (Table 7 of Appendix B). Drill a hole in a 4 X 4 wood block. The hole size is dependent upon the primer used. The hole size should accommodate the primer and enable exhaust from the ignited primer to be expelled at the opposite end of the block. Secure the wood block and the actuator piston so that the stroke of the piston will hit the primer in an extended position.

TEST PROCEDURE

1. Charge the accumulator, item 11, to 180 psi.
2. Open both manual ball valves, item 4, and adjust the regulator valve, item 5, to 10 psi. Recharge the accumulator as necessary. Record the regulated output pressure from the pressure gauge, item 8.
3. Place a primer in the wood block.
4. Close both ball valves.
5. Charge the accumulator to 10 psi and record the pressure.
6. Quickly open the ball valve before the regulator.
7. Record the results of primer ignition (yes or no).
8. Close the ball valve.
9. Open the ball valve after the regulator valve. This will relieve the pressure in the actuator piston.
10. Close the ball valve.
11. If ignition does not occur, repeat steps 1 through 10 with incremental increases in regulator pressure of 5 psi each.
12. Replace the primer.
13. Repeat steps 6 through 12 until no more positive actuation occurs.
14. Replace the primer and repeat steps 4 through 13 with 10 psi incremental increases in accumulator charge pressure until 180 psi (example: repeat test with accumulator pressures of 10 psi, 20 psi, 30 psi, etc.).

TEST 2

OBJECTIVE

Explore the performance of the intensifier.

SETUP

Construct a system as shown in Appendix A, Figure 21, Test Schematic #2, using components as called for in the bill of materials for Test 2 of Appendix B.

TEST PROCEDURE

1. Set the regulated output of the compressor to 25 psi.
2. Record intensifier input flow.
3. Connect the shop compressor to the test system.
4. Open the manual valve.
5. Record hydraulic pressure and flow every 5 seconds until pressure reaches 3,000 psi.
6. Repeat steps 1 through 5 for 35 psi, 45 psi, 55 psi, 65 psi, 75 psi, 85, psi and 95 psi shop compressor outputs.

TEST 3

OBJECTIVE

Verify that a series-parallel arrangement of three binary valves will sequence the actuation of four pneumatic air cylinders.

SETUP

Construct a system as shown in Appendix A, Figure 20, Test Schematic #1, using components as called for in the bill of materials for Test 1. In addition to this setup, insert a binary valve between the pressure relief valve and air cylinder. An additional air cylinder will need to be added to the exit port of the binary valve.

TEST PROCEDURE

1. Connect air compressor to input port of binary valve.
2. Connect 6 inches of pneumatic tubing to each output port of binary valve.
3. Connect pressure relief valve to each output port tube.
4. Connect 3 inches of pneumatic tubing to each pressure relief valve.
5. Connect pneumatic air cylinder to each output port tube.
6. Set air compressor pressure regulator to 20 psi.
7. Pressurize the binary valve.
8. Record the actuation of the first air cylinder.
9. Open the pressure relief valve that is connected to the actuated air cylinder.
10. Record the shifting of the binary valve.
11. Close the pressure relief valve.
12. Pressurize the binary valve.
13. Record the actuation of the second air cylinder.

TEST 4

OBJECTIVE (PART 1) (NOTE: this is a two part test)

Determine the optimum gas pressurization of the Bimba accumulator to successfully fire four sodium azide/copper oxide fuel cartridges.

SETUP

Construct a system as shown in Appendix A, Figure 20, Test Schematic #1, using components as called for in the bill of materials for Test 1. Drill a hole in a 4 X 4 wood block. The hole size should accommodate the primer and enable exhaust from the ignited primer to be expelled at the opposite end of the block. Secure the wood block and the actuator piston so that the stroke of the piston will hit the primer in an extended position.

TEST PROCEDURE

1. Close all valves in the test setup.
2. Pressurize the Bimba accumulator to 5 psi with air supplied from air compressor.
3. Position a firing cap on a secured mounting so that the air cylinder pin will strike the firing cap.
4. Release shutoff valve to allow pressurized air from Bimba accumulator to actuate the air cylinder.
5. Open pressure relief valve to return air cylinder pin to its original position.
6. Check for ignition of firing cap.
7. If ignition of the primer occurs, lower the Bimba accumulator pressure by 1 psi.
8. Close all valves in the test setup.
9. Repeat steps 3 through 6.
10. If firing does not occur, increase Bimba accumulator pressure by 5 psi.
11. Close all valves in the test setup.
12. Repeat steps 3 through 6.
13. Record results.

OBJECTIVE (PART 2)

Test for the number of ignitions possible with a maximum Bimba accumulator pressure of 180 psi.

SETUP

Construct a system as shown in Appendix A, Figure 20, Test Schematic #1, using components as called for in the bill of materials for Test 1.

TEST PROCEDURE

1. Set flow regulator to pressure obtained from Test 4.
2. Close all valves in the test setup.
3. Charge Bimba accumulator to 180 psi with air supplied from compressor.
4. Release shutoff valve to allow pressurized air from Bimba accumulator to actuate air cylinder and ignite firing cap.
5. Replace firing cap.
6. Close shutoff valve.
7. Open pressure relief valve to return air cylinder pin to its original position.
8. Close pressure relief valve.
9. Record Bimba accumulator pressure.
10. Record firing cap ignition.
11. Repeat steps 4 through 8.
12. Repeat process until Bimba accumulator pressure is not high enough to ignite firing cap.

TEST 5

OBJECTIVE

Determine the regenerative cycle of the accumulator.

SETUP

Use a constant 125 psi shop air to charge the intensifier, referring to the system shown in Appendix A, Figure 21.

TEST PROCEDURE

1. Set the regulated output of the shop air compressor to 125 psi.
2. Precharge the accumulator to 1,000 psi.
3. Connect the compressor to the system at the 1.25 inches National Pipe Thread (NPT) male charge port.
4. Start the compressor. Open the manual valve after the compressor has been fully charged.
5. Record the time it takes the intensifier to charge the accumulator from 1,000 psi to 2,500 psi.

TEST 6

OBJECTIVE

Determine the fluid characteristics of the gas given off by the fuel cartridges by measuring a single cartridge output: pressure, flow rate, and temperature in a special test setup.

SETUP

Test 6 will require a special test setup, as shown in Figure 22 of Appendix A, to gather all the data required. A pressure transducer will be used to measure the pressure in the test setup. Because the pressure will vary erratically, a pressure transducer will be wired to a datalogger for testing. The datalogger will record the variation of the pressure against time, allowing us to see how the pressure varies with time and how long the pressure spike lasts.

Due to the high temperatures involved, the pressure transducer will need to be isolated from the pressure source by a short length of tubing or pipe.

For a gas temperature of 1,700 ^{O}F, the tubing needed is 8 inches long, assuming type 303 stainless-steel with a 0.25 inch outer diameter and a 0.18 inch inner diameter is used.

The pressure transducer may also need a stainless-steel membrane to resist the temperatures developed by the burning fuel. When utilizing steel membrane transducers, amplifiers are often needed due to the low output voltage (3 millivolts out for every 1 volt in).

A Potts flow meter will be utilized to measure the flow rate of the gas given off by the cartridge. This will also interface with a datalogger and the logger will record the variation of the flow rates as the test progresses. The Potts flow meter is a turbine type flow meter that outputs a voltage.

The voltage output depends on how fast the turbine is spinning. The temperature of the gas will be high enough that type K thermocouples will need to be used. Type K thermocouples with 0.032 inch diameter have a maximum extended service temperature of 1800 degrees Fahrenheit which is within our temperature range. The test setup will consist of a pipe the same length as the gas generator body and also the same diameter as one of the fuel cartridges. This pipe will be securely bolted to the test table with the exhaust end of the pipe facing a safe direction.

One type K thermocouple will be used to determine the temperature near the fuel cartridge and also near the inlet to the intensifier (the end of the tube).

A Potts flow meter will be mounted inside the pipe to measure the flow rates. The flow meter will be mounted near the end of the pipe so that the gasses will have a chance to cool. The pressure transducer will be mounted on a pipe or tube eight inches long that is mounted perpendicular to the larger test pipe. The transducer is mounted in this way because of the reasons previously discussed.

TEST PROCEDURE

1. Install fuel cartridge into test pipe.
2. Secure fuel cartridge with firing mechanism cap.
3. Place type K thermocouple into test pipe near cartridge and secure.
4. Place type K thermocouple into test pipe near intensifier entrance and secure.
5. Mount pressure transducer to isolation pipe and secure.
6. Install Potts turbine type flow meter into test pipe and secure.
7. Mount test setup to testing bench.
8. Wire thermocouples to multimeters.
9. Wire pressure transducer to datalogger.
10. Wire Potts flow meter to datalogger.
11. Pressurize Bimba accumulator to 50 psi.
12. Throw gate valve to release pressure and ignite the fuel cartridge.
13. Record data from multimeters and from dataloggers.
14. Release pressure from Bimba accumulator.
15. Remove firing mechanism cap.
16. Replace fuel cartridge.
17. Secure firing mechanism cap.
18. Repeat steps 11 through 17.

TEST 7

OBJECTIVE

Determine the regenerative cycle of the accumulator using solid fuel cartridge as gas source.

SETUP

Replace the shop air used in Test 5 with the firing of a single solid propellant cartridge.

TEST PROCEDURE

1. Disconnect the air supply from the compressor to the intensifier from test #5.
2. Attach the gas generator body, including the filter, and gas regulator to the gas intake port of the intensifier.
3. Attach a single cartridge holder, cartridge, and firing chamber to the gas generator body.
4. Set up output side of intensifier and accumulator in the same way as Test 5.
5. Check that the accumulator is precharged to 1,000 psi in order to prevent damage to the inner bladder.
6. Using an actuator setup, fire a single cartridge from the firing chamber to charge the intensifier.
7. Record the time and pressure every 5 seconds until intensifier has charged the accumulator from 1,000 psi to 2,500 psi.

TEST 8

OBJECTIVE

Evaluate the muffler heat exchanger design measuring the discharge pressure and temperature when Test 6 is repeated with Test 5 setup attached to it. The exhaust should be emitted at 100 ^{o}F and atmospheric pressure.

SETUP

The test setup will consist of Tests 5 and 6 combined. A solid fuel cartridge will be fired in Test setup #6 with the intensifier and accumulator attached, along with the muffler heat exchanger.

The muffler heat exchanger will be attached to the gas discharge port of the intensifier. While Test #6 will be attached to the intensifier gas input port. Testing will consist of measuring the exhaust temperature and pressure of the gas emitted by the solid fuel cartridge. The exhaust temperature should be 100 ^{o}F at a pressure of 14.7 psi.

A thermocouple will be used to measure the heat out of the muffler heat exchanger. The thermocouple will be wired to either a multimeter or a thermocouple reader, and the data will be recorded by hand. The pressure out of the muffler heat exchanger will be measured by a pressure transducer.

A datalogger will be used to read the output of the pressure transducer, and record it. If the temperature is not found to be low enough, more hydraulic fluid from the accumulator will be counter flowed through the muffler heat exchanger. The test will be repeated until the desired temperature of 100 degrees Fahrenheit (^{o}F) is obtained.

TEST PROCEDURE

1. Attach the muffler heat exchanger to test setup #5.
2. Attach test setup #6 to test setup #5.
3. Firmly attach test #8 setup to work bench.
4. Secure all hoses and tubing to the test bench.
5. Attach thermocouple to muffler heat exchanger.
6. Mount a pressure transducer on the muffler heat exchanger.
7. Connect thermocouple to either multimeter or thermocouple reader and verify power.
8. Connect the pressure transducer to the datalogger and verify power.
9. Verify off position of hand valves.
10. Insert solid fuel cartridge into test pipe.
11. Attach firing mechanism cap to test pipe and verify fit.
12. Charge Bimba accumulator to 50 psi.

13. Put on eye protection.
14. Turn firing valve.
15. Record thermocouple output voltage.
16. Record datalogger data and reset.
17. Read accumulator pressure and record.
18. Turn pressure relief hand valve to vent actuator pressure.
19. Remove firing mechanism cap.
20. Remove spent fuel cartridge.
21. Insert new fuel cartridge.
22. Vent pressure from large accumulator.
23. Install firing mechanism cap and secure.
24. Repeat steps 13 through 23.

TEST 9

OBJECTIVE

The objective of this test is to evaluate the performance of the filter and the regulator.

SETUP

Construct a system as shown in Appendix A, Figure 23, Test 9 Schematic, using components as called for in the bill of materials for Test 9. The test setup consists of a series of equipment whose basic function will be to activate the piston as described in previous tests.

Other major components of this test are the gas generator, intensifier, filter, and regulator, the last two being the focus of this test. The filter will be used to extract unwanted particulates from the gas before it enters the intensifier. It is desirable that the intensifier operates at 75 psi; therefore, the pressure must be regulated to meet this requirement.

TEST PROCEDURE

1. Charge the Bimba accumulator to 180 psi using the compressor as shown.
2. Open both manual ball valves and adjust the regulator value to 10 psi. Recharge the accumulator as necessary.
3. Close the ball valve.
4. Charge the accumulator to 10 psi.
5. Quickly open the ball valve.
6. If the primer does not fire, repeat steps 4 and 5 until the primer does fire. Gradual increases of pressure in the accumulator may be necessary. **NOTE:** Be sure to record the pressure necessary to fire the cartridge.
7. Record the values of P1, P2, F1, and T1, which will be located as shown in the test schematic (Appendix A, Figure 23).
8. Remove the filter and record observations.
9. Replace the filter and firing cartridge and repeat steps 1 and 2.

TEST 10

OBJECTIVE

The objective of this test is to evaluate the performance of the overall system.

SETUP

The test setup will be the same as for Test 9 with the addition of the muffler heat exchanger, the hydraulic sump, hydraulic fluid, another accumulator, the hydraulic motor, and various fittings and components.

TEST PROCEDURE

1. Charge the Bimba accumulator to 180 psi using the compressor as shown.
2. Open both manual ball valves and adjust the regulator value to 10 psi. Recharge the accumulator as necessary.
3. Close the ball valve.
4. Charge the accumulator to 10 psi.
5. Quickly open the ball valve.
6. If the primer does not fire, repeat steps 4 and 5 until the primer does fire. Gradual increases of pressure in the accumulator may be necessary. **NOTE:** Be sure to record the pressure necessary to fire the cartridge.
7. Record the pressure of the hydraulic fluid in the accumulator.
8. Record the output of the hydraulic motor.

CALCULATIONS

Calculations were performed to assist in the optimization of the final design and the procurement of components and to provide a basis for comparison of test results necessary for sizing system components.

The gas volume and burning rate per weight of fuel is necessary to size the fuel cartridges. The fuel used in this application is a slow-burning derivative of the chemical compound sodium azide - copper oxide that expels nitrogen gas. The gas pressure produced by this fuel will be determined by the amount of fuel and the total volume of the system.

Calculations of the total gas generator system volume utilizing different flow devices are important in determining the need for and size of an accumulator. Inlet and exit pressures of various orifices and venturies were calculated to provide evidence of the optimal choice in flow regulation and assistance in determining the system pressure requirements.

The striking force provided by the firing head enabling ignition of the fuel cartridges is determined by the spring mechanism of the firing head. The determination of the spring constant necessary for ensuring ignition is essential in obtaining the correct size spring for the firing head.

Calculations of heat transfer on the muffler heat exchanger determined the necessity of utilizing the hydraulic fluid to remove exhaust heat. This hydraulic fluid is pumped into the muffler heat exchanger in a counter-flow direction.

Calculations were performed to determine system performance for nitrogen at high temperatures. Testing of the gas generator system and each of its components determines the system's performance at ambient temperatures.

DISCUSSION OF RESULTS

The sequential progress of the construction, testing, and fabrication of this project is depicted in the charts shown in Figures 18 through 21 of Appendix A. Table 8 of Appendix B shows the engineering formulas used in the analysis of the gas generator and component system performance.

1) FIRING MECHANISM

Considering the requirements listed below, a decision matrix was developed to produce the optimal design of the firing mechanism:

* Reliability
* Maintainability
* Simplicity
* Durability
* Safety
* Size

The five (5) options presented for the design of the firing mechanism are:

1. Rotating Firing Mechanism Head.
2. Rotating Firing Mechanism Chamber.
3. Automatic Arrangement with Clip.
4. Bolt Action.
5. Pneumatic Pistons with Binary Valving.

This decision matrix, presented as Table 9 in Appendix B, shows that the major factors in consideration of this design are its safety, how easy it is to operate (load and ignite the fuel), and how well it meets the size requirement. This matrix shows that the rotating firing mechanism head renders the optimum design of a firing mechanism for this system. An optimum percussion force of 27.5 pounds was determined to be the most consistent and reliable (at least 95 percent confidence level). Figure 24 corresponds to the schematic shown in Figure 20 for Test 1. Table 10 of Appendix B shows the results of Test 1.

After many failed attempts to ignite a primer, corrective actions were initiated. As shown in Figure 25 of Appendix A, the piston end was sharpened to reduce the area of contact and provide more pressure (force x area). The piston stroke length was increased to provide more momentum as shown in Figures 26 and 27 of Appendix A. Head loss was reduced to provide a greater force on the primer. This was achieved by removing the regulating gauge, regulated pressure gauge, tubing, union tees, and piston pressure relief valve. Figures 28 and 29 of Appendix A show the system with and without these components. A plate was added, Appendix A, Figure 30, to provide additional structural integrity and impact force on the primer. Finally, the hole in which the primers are placed was bored and a hardened dial was inserted. The dial was then bored the same size of the primer. As shown in Figure 31 of Appendix A, this provided additional pressure around the primer.

The effects that each of these changes had on the successful or failed ignition of the primers are shown in the summary table (Table 10, Appendix B). Figure 32 of Appendix A shows a group of successfully ignited primers. Three different brands of primers were tested. They included primers manufactured by CCI, Winchester, and Federal.

The firing mechanism was connected to two Bimba accumulators rated at 300 psi each. Connections were made via poly-tubing and brass fittings. All components were securely fastened to the work station. A hole was drilled in the handle of the firing mechanism valve and a cable attached in order to remotely operate the firing mechanism as a safety precaution.

An empty 12-gauge shot gun shell was fabricated to fit the firing mechanism in order to test the system prior to insertion of an actual fuel cartridge. The remote operation was successful.

A fuel cartridge was inserted into the firing mechanism and the head secured. The lab area was cleared and a cartridge was then fired using the remote system. Ignition of the cartridge was successful.

In less than one second, an explosion was heard and the lab area was filled with "smoke." After about three seconds, the thermocouple in the firing mechanism was reading 717 ^{o}F. A pressure reading was not acquired due to the lab conditions.

Upon examination of the firing mechanism apparatus, it was found that the poly-tubing had failed and the firing piston was fractured at the threaded connection. Examination of the tubing showed that the failure was a combination of heat and pressure. The tubing was not melted but split.

A different configuration firing mechanism head was fabricated. This head used a small hardened pin, similar to that of a pistol. This prevented the "blow back" force of the primer from acting against the actuator piston. This reactive force was thought to be the cause of the thread failure in the actuator body. A sketch of the refabricated head is shown in Figures 33 and 34 of Appendix A.

All poly-tubing was upgraded to stainless-steel tubing and the two Bimba accumulators were exchanged with a 116 cubic-inch accumulator. This setup is shown in Figure 35 of Appendix A. All test and actual cartridge ignitions were successful after these changes.

2) SOLID FUEL CARTRIDGES.

The purpose of the solid fuel is to provide gas to the intensifier. The four major design considerations of the fuel cartridges are:

* Easy replacement
* Availability from multiple suppliers
* Long shelf life
* Safe discharge into the environment

The size of the cartridges is important due to system charging requirements. Table 11 of Appendix B shows a matrix of the five possible fuels that may be utilized in the design of this system. They are:

1. Hydrazine
2. Rubber Ammonium Nitrate
3. Sodium Azide - Copper Oxide (slow-burning)
4. Compressed Air
5. Sodium Azide - Copper Oxide (fast-burning)

This matrix has been developed to provide an optimal choice in selecting a fuel that meets or exceeds the gas generator system's requirements. The results of this matrix show that the slow-burning sodium azide - copper oxide fuel has a distinct advantage over the other fuels.

Tables 12, 13 and 14 of Appendix B show the propellant properties of rubber ammonium nitrate and fast-burning sodium azide - copper oxide fuels respectively. The propellant data sheets from Talley Defense Systems show that the trade name TAL-1104 is fast-burning while TAL-1101 MOD, shown in Tables 1 and 2, is the slow-burning sodium azide - copper oxide fuel.

Table 15 of Appendix B shows a list of propellant suppliers that were contacted to obtain a suitable power cartridge for testing and evaluation. With the exception of Stresau Laboratories, Inc. of Wisconsin and ICI, Toronto, most suppliers were reluctant to discuss small quantity purchases. Test cartridges were obtained from Stresau Laboratories, Inc.

Testing of the sodium azide - copper oxide propellant cartridges showed that a buildup of copper was present at all connection points. The pressure gauge in the firing mechanism was located at the end of the accumulator. This caused a buildup of copper in the pressure gauge fitting entrance.

It was thought that since this buildup occurred, an accurate pressure reading was not available. Figure 36 of Appendix A, shows this buildup. Pressure readings averaged 52 psi. The pressure gauge was also probably effected by the heat from the ignited cartridges. Temperature readings from a thermocouple located in the firing mechanism showed an average of 823 ^{o}F.

The pressure gauge was replaced and relocated to the front side of the accumulator. Removal and inspection of this gauge showed no copper buildup and no damage. The gauge in this location was not subjected to the direct heat and dynamic pressure loads and thus removed from the flow path of the expanding gas created from the ignited cartridge.

It was noted that a pressure spike of about 225 psi was indicated on the gauge in this location. Readings from the gauge in this location indicated that the pressure averaged 110 psi. Table 16 of Appendix B shows the results of the five tested fuel cartridges.

Evaluation shows that the power cartridges tested contain 23 grams of sodium azide - copper oxide and produce 116 cubic inches of nitrogen gas at 83 ^{o}F and a pressure of 110 psi. A gas input of 75 psi at a flow rate of 14 scfm takes 15 seconds for the intensifier used in this application to recharge a one gallon bladder accumulator from 500 psi to 2,500 psi.

The hydraulic motor, manufactured by Webster, will deliver one horsepower in the range of 500 to 2,500 psi hydraulic intake pressure. This equates to approximately 955 grams of sodium azide - copper oxide required for recharging the accumulator. It is important to note that the energy density and chemical formulation of the compound that were tested produced these results. Slight changes in grain size and percentage of each element significantly effect the reaction of the compound.

3) GAS GENERATOR BODY

The prerequisites of the gas generator body are that it captures the gas produced from the ignited solid fuel cartridges and directs the gas flow into the filter. The major design features of the gas generator body that are considered include:

* Pressure Drop
* Space Requirements
* System Adaptability
* Connectability to the firing mechanism and filter
* Ability to resist impingement from the ignited solid fuel cartridges

Tables 17 and 18 of Appendix B, show matrices that evaluate the following seven shapes and six materials suggested for this design:

SHAPES

* Smooth Curve
* Straight
* 45° Bend
* Concentric
* Curved Nozzle
* 90° Nozzle
* Right Angle

MATERIALS

* Mild rolled steel A-36
* Stainless-steel; Type 305
* Nylon 6/6
* 0.3 percent Carbon Steel
* Aluminum 6061 T-6
* UHMW Polyethylene

The results of these matrices show that an optimal design would be achieved by utilization of a concentric shape made of stainless-steel (type 304). Stainless-steel (type 305) was suggested for use because of its higher corrosion resistance. However, type 305 stainless-steel was not commercially available. Type 304 is available from multiple suppliers.[19,20] Type 304 is also the material suggested by filter and flow controller manufacturers.[21,22]

The disadvantage of type 304 stainless-steel is its density. Therefore 6961-T-6 aluminum was used for the prototype configuration.

4) FILTER

Because of the contaminates released during the combustion process, the gas produced must be cleaned so it will not contaminate the remaining system. The available types of filtering media considered for this system include:

* Cloth
* Paper
* Metal and Fiberglass Screen
* Ceramic and Porous Metals

A paper media was eliminated in analysis due to the temperature requirement of the burning fuel. Paper filters are inexpensive and provide good filtration but have poor strength and resistance to heat. Depending on the fuel used, temperatures of approximately 2,100 °F will be produced.

A matrix of the filtering media is shown in Table 19 of Appendix B. This matrix evaluates these different media with major consideration given to its filtering ability, reliability, and flow resistance. Table 19 shows that a metal (Hastoly or Inconel) screen type filter would provide the optimal design.

Appendix F provides data supplied by filter manufacturers. Analysis of this data shows that a Plain Dutch or Twilled Dutch wire metal weave would provide filtering, gas flow, pressure resistance, impingement ability, and heat resistance as required by the gas generator system.

5) PRESSURE REGULATOR

A pressure regulating device is required to regulate the flow of gas exiting the filter and to supply a steady input pressure to the intensifier. The intensifiers to be utilized require an input pressure of approximately 75 psi at a flow rate of 14 scfm. Size is also an important factor in choosing this component.

The five designs suggested for utilization on flow and pressure regulation are:

* Cavitating Venturi
* Sharp Edged Orifice
* Nozzle
* Flow Rate Controller
* Reducing Valve

A matrix evaluating the performance of these different regulating devices is shown in Table 20 of Appendix B. This evaluation included major considerations to a steady flow output, adaptability to the filter and transition piece, the pressure drop produced, and maintenance of the component itself.

This evaluation shows that a flow rate controller will provide the system with optimum results. Appendix E provides data supplied by W.A. Kates Co. [22] on the operation and performance of a flow rate controller.

6) INTENSIFIER

The purpose of the intensifier is to increase the gas generator system's pressure. Gas enters the intensifier at a pressure of 50 to 100 psi, and through the exchange of different sized pistons, exits the intensifier at pressures to 4,000 psi. The particular intensifier used in the design of this prototype has a 40:1 pressure increase ratio. This intensifier is manufactured by Hydronics Corp.[25] The optimization of this component is based on considerations of performance, cost, and weight.

Tested results from the intensifier are shown in Table 21 of Appendix B. These results are for a constant air input of 14 standard cubic feet per minute at a pressure of 75 psi.

Table 8 of Appendix B shows the engineering formulas used in the analysis of the gas generator and component system performance.

The hydraulic motor was placed in line with the intensifier and accumulator. The intensifier was supplied with air from a 220 volt, 5 horsepower, 60 gallon, single-stage compressor with a regulated output of 75 psi.

The system was charged to 650 psi before the motor started to turn. The motor ran freely (no load), depleted the system down to 200 psi and then stopped. The intensifier was still being charged with shop air, and the system pressurized to about 1,200 psi before the motor started turning the second time. The system again depleted down to about 200 psi before the motor stop turning. This procedure repeated two more times (1,200 psi motor start -200 psi motor stop). On the third charge to 1,200 psi, the motor would not start. The system was charged to 1,500 psi, and there was no reaction.

The system pressure was slowly increased to 3,000 psi and still there was no reaction (motor did not turn). The system was shut down at 3,000 psi for fear of a high-pressure accident.

The motor shaft was lightly tapped to try to unbind the motor, but there was no reaction. The system pressure was then very slowly depressurized at the accumulator entrance coupling. After about three hours, the system pressure was depleted to about 250 psi, and the motor was again tapped. The motor turned and depleted the system down to about 100 psi.

John Lynaugh, the sales representative for the motor, was contacted to acquire expert advice from the motor's supplier - Adams Air Hydraulics, Tampa, FL.

After discussion with the design team, it was decided to retest the system with the motor loaded and only after the motor was performance checked with the manufacturer. This may have been a defective motor. The motor's published performance curves (see attached-Model M29YB) show that the motor will deliver one horsepower down to an input range of about 500 psi, but this is not what was experienced.

A relief (bleed) valve will be inserted into the system before any more testing proceeds.

OBSERVATIONS

The analysis of the gas generator system raised many questions as to how to create a complete and working prototype. Selection of the fuel size and quantity affected the design of the remaining system because of the volume of gas produced, which is directly related to the pressures throughout the entire system. The selection of the firing mechanism was directly proportional to the fuel size and quantity. Filter and flow controller selection was dependent upon the fuel and firing mechanism design. All these parameters were adapted to each other to optimize the design.

It is estimated that the volume of fuel generated was compatible with the internal volume of the gas generator system. The need for an additional component, a holding accumulator, was indicated. Figure 3 of Appendix A offers a gas generator system schematic to meet the need of an accumulator to store excess energy required.

1) FIRING MECHANISM.

The firing mechanism should utilize four solid fuel cartridges as described above and be designed according to the option of the firing mechanism with pneumatic pistons and binary valving. The material selected for the firing mechanism was compatible to the gas generator body. The input device used to signal ignition is mechanical, and no electronics are used.

A statistical analysis of the results of Test 1 show that a primer will be ignited at an accumulator pressure of 30 psi with a 95 percent confidence interval. This analysis is shown in Table 10 of Appendix B.

The testing of the primers showed several factors that were given consideration to a successful ignition were not significant. The addition of a plate, reduction in head loss, and increased accumulator pressure had little or no effect on the ignition success rate.

Piston speed (momentum), manufacturer, and primer surrounding compressive forces all had a positive effect on the ignition success rate. Table 22 of Appendix B shows piston velocity as a function of cylinder input flow and cross-sectional area.

The solid fuel cylinders tested were fabricated with a metal sleeve that adds compressive forces to the primers, much like the addition of the hardened wood dial in Test 1 (see Figure 31 of Appendix A). The primers loaded into the fuel cylinders were manufactured by FEDERAL and a factor of safety of two was included in the ignition accumulator pressure, which equates to a required pressure of 60 psi.

Upon testing of the ignition system to determine the optimal accumulator pressure (maximum number of ignitions per a certain accumulator pressure), the ignition system was placed in line with the intensifier exhaust. A schematic of this setup is shown in Figure 37 of Appendix A. The theory is to utilize the intensifier's exhaust to regenerate the accumulator pressure, and at the same time, add a heat sink to the exhaust gas. This eliminates the need to produce multiple ignitions from the same accumulator charge.

Testing of the intensifier showed that the exhaust pressure is approximately equal to ambient pressure. Therefore, the regeneration of the accumulator pressure can be achieved by tapping the intensifier air intake as shown in Figure 38 of Appendix A.

Leaving the actuator pistons in the extended position after ignition eliminates the need for a return pressure mechanism and simplifies the design. The pressure that maintains the extended piston position was relieved by the opening of a solenoid valve upon replacement of the solid fuel cartridges. This also adds a safety feature that disables the cartridges from accidently being ignited.

2) SOLID FUEL CARTRIDGES.

The gas generator system uses four cylindrical fuel cells, 1.375 inches in diameter and 2.625 inches in length. These solid fuel cartridges may be supplied in a cylindrical configuration as shown in Figure 39 of Appendix A. This will simplify the supply and replacement of the cartridges. The design team advocates that these cartridges be made of a cold-compressed slow-burning sodium azide - copper oxide compound in an aluminum casing with a 5 micron filter in each cylinder. This corresponds to Talley Industries' propellant known as TAL-1101M. It is interesting to note that previous problems with TAL-1101M resulted with moisture interaction with a copper casing, resulting in the formation of copper azide, which contributes to instability in the compound.

3) GAS GENERATOR BODY.

Fabrication of the gas generator body with 6061-T6 aluminum and a concentric shape will allow the head of the firing mechanism to be horizontally or vertically mounted.

Stress analyses were conducted to calculate the gas generator body wall thickness. The maximum pressure was unknown at the time and therefore considered a variable. Stress analyses for the gas generator body required two equations. The thin walled pressure vessel equation is valid for a thickness to diameter ratio of 1:20. For ratios greater than 1:20 Lame's [26] equation is utilized. These analyses are shown in Table 23 of Appendix B and displayed in Figure 40 of Appendix A.

4) FILTER.

Filters made of Hastoly or Inconel were fabricated with a 165 by 1,400 Dutch weave mesh in a cylindrical shape. They were placed at the inside tip of each fuel cylinder to provide the required filtration, heat resistance, and resistance to impingement. Filter material was obtained from Michigan Dynamics, Inc. Their data and qualifications are shown in Appendix F.

5) PRESSURE REGULATOR.

Discovery of a flow rate controller was required for the pressure regulation device. An adjustable flow regulator was used during testing of the gas generator system. Appendix E furnishes data from Kates Company on this component. A prototype fixed rate controller may be designed for future use.

6) INTENSIFIER.

Hydronics Corp. was solicited to supply the intensifier. A horizontally mounted model was obtained and exceeds the system requirements in that the horizontal mount provides for better spatial arrangement and is self contained with a hydraulic reservoir and sump. A reservoir and sump, which are not in the scope of the gas generator system design, would also be needed if not contained in the intensifier. The model number for this component is HEYPAC:GX-40-SSN-RH.

Table 21 of Appendix B shows that the data collected on the intensifier performance fits a 5^{th} Order equation. Figure 41 of Appendix A depicts the intensifier output flow versus hydraulic pressure for a gas input pressure of 75 psi at a flow rate of 10 standard cubic feet per minute. Altering either the gas input pressure or flow rate produces a family of curves parallel to that shown in Figure 41.

The power developed by the hydraulic motor is a function of the intensifier output fluid flow rate and the hydraulic pressure. Table 24 of Appendix B shows the relationship between power, flow rate, and hydraulic pressure.

In future design, the firing mechanism will be welded to the gas generator body. All other components be fabricated with permanent connections wherever possible. This eliminates the possibility of leakage. Mandatory maintenance and replacement components may have removable connections, but must be designed with seals to prevent leakage.

A design problem occurs with the rigid connection of this system's components because of seal requirements. The system is tested to meet 3,000 psi and a production model would have a factor of safety of two which equates to a 6,000 psi system. This also creates problems where system maintenance is a consideration. Therefore, it is recommended that the firing mechanism be fabricated to include the hardware as shown in Figure 42 of Appendix A. Removal of the Teflon washer will provide enough separation in the system to perform any necessary maintenance.

The gas generator system was fabricated according to the specifications outlined in the Specifying Goals Report [11] found in Appendix D. A test plan was developed and a system prototype as shown in Figure 43 of Appendix A was constructed and tested.

ACKNOWLEDGMENTS

The UCF Gas Generator Design Team expresses their appreciation to Dr. Loren A. Anderson from the University of Central Florida for his guidance, leadership, and knowledge while researching and developing this system.

The Gas Generator Design Team acknowledges Mr. Otto H. Fedor of NASA-KSC (retired) for sharing his invaluable wealth of information, his encouragement, and the previous work, which has been the foundation of this project.

The team thanks the following companies and persons for their assistance in the research and development of this system:

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Michigan Dynamics, Inc. - Garden City, Michigan
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Mr. Fritz Meier - East Coast Machine, Inc. - Rockledge, FL
Mr. Allen R. Jobes - Hydraulic House, Inc. - Orlando, FL
Mr. John Lynaugh - Adams Air Hydraulics - Tampa, FL
Mr. Wayne Hanson - Stresau Laboratories, Inc. - Spooner, WI

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23. Notes and Sketches from Mr. Otto H. Fedor; National Aeronautics and Space Administration, Kennedy Space Center at University of Central Florida, Orlando, FL, August 29 and September 5, 1991.

24. Conversation with Mr. Otto H. Fedor; National Aeronautics and Space Administration, Kennedy Space Center at University of Central Florida, Orlando, FL, November 12, 1991.

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APPENDIX A

FIGURES AND SKETCHES

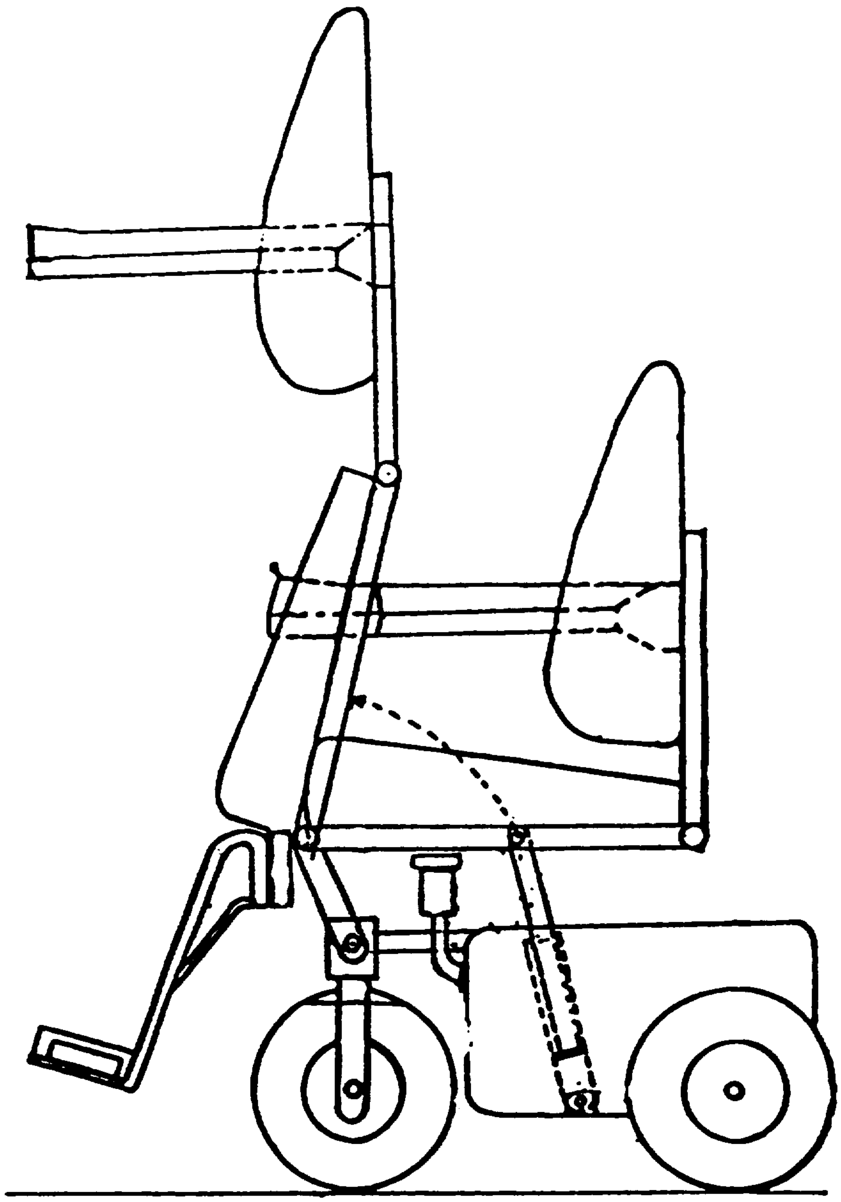


FIGURE 1
POWERED WHEEL CHAIR (PMS)

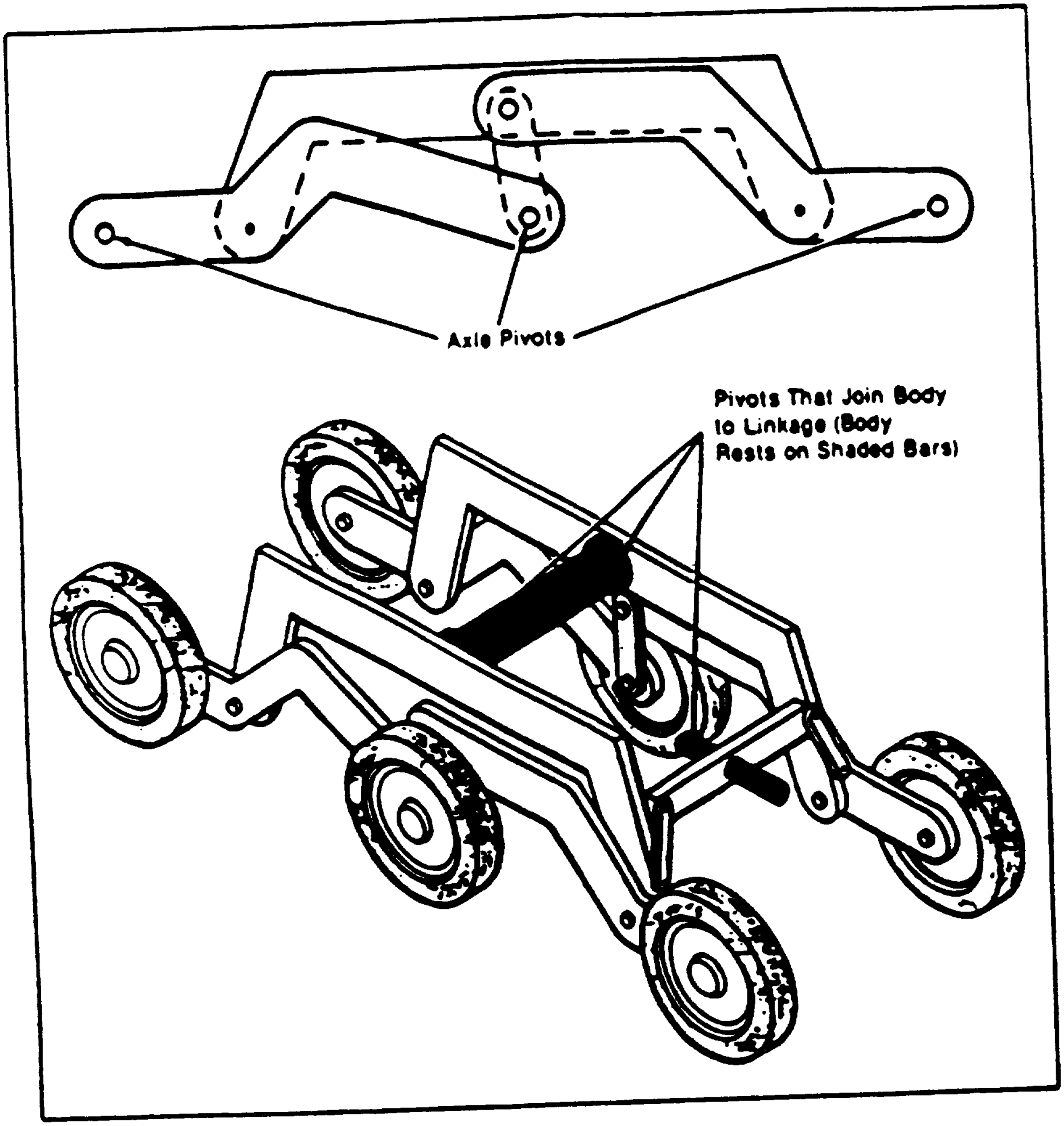
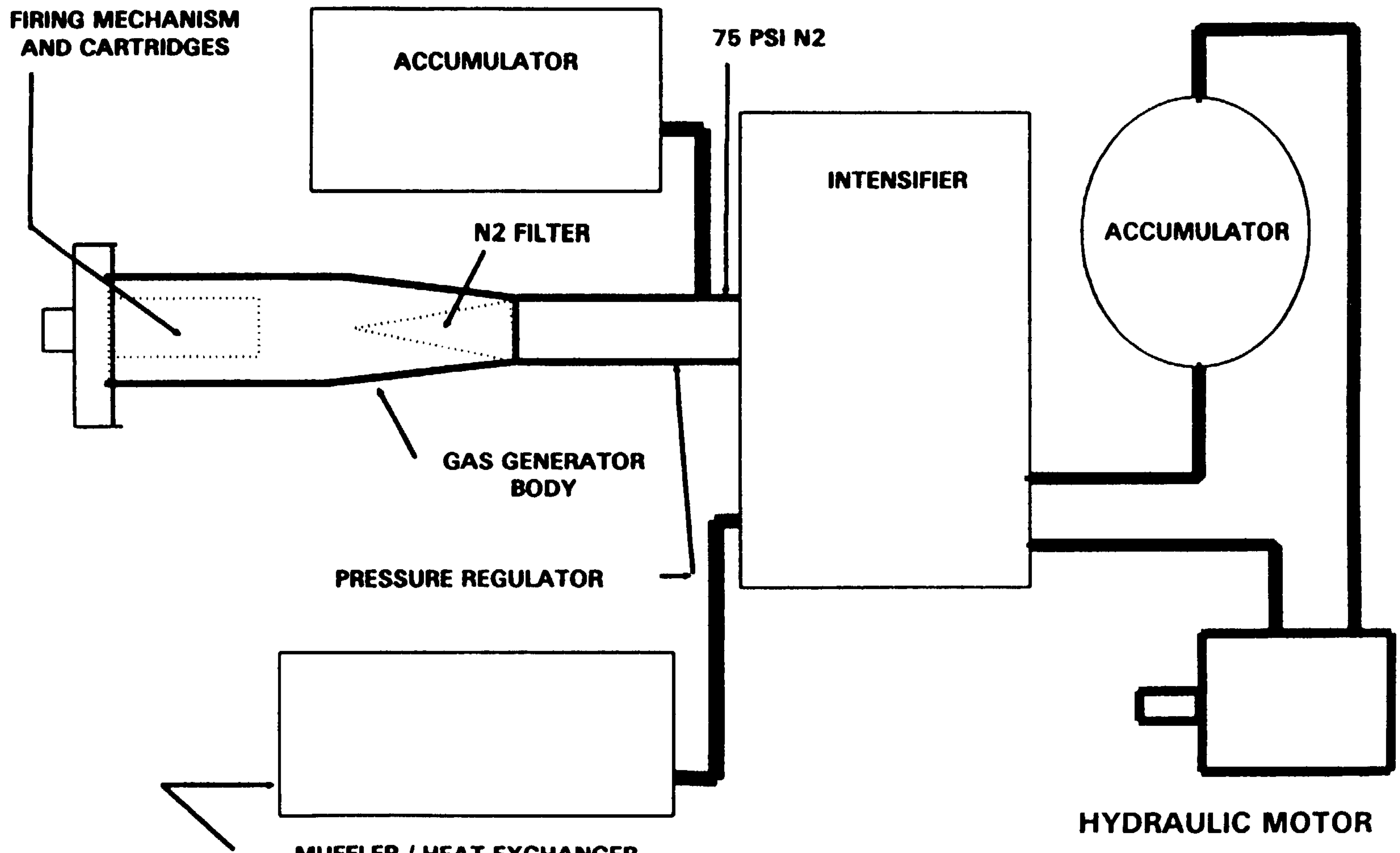
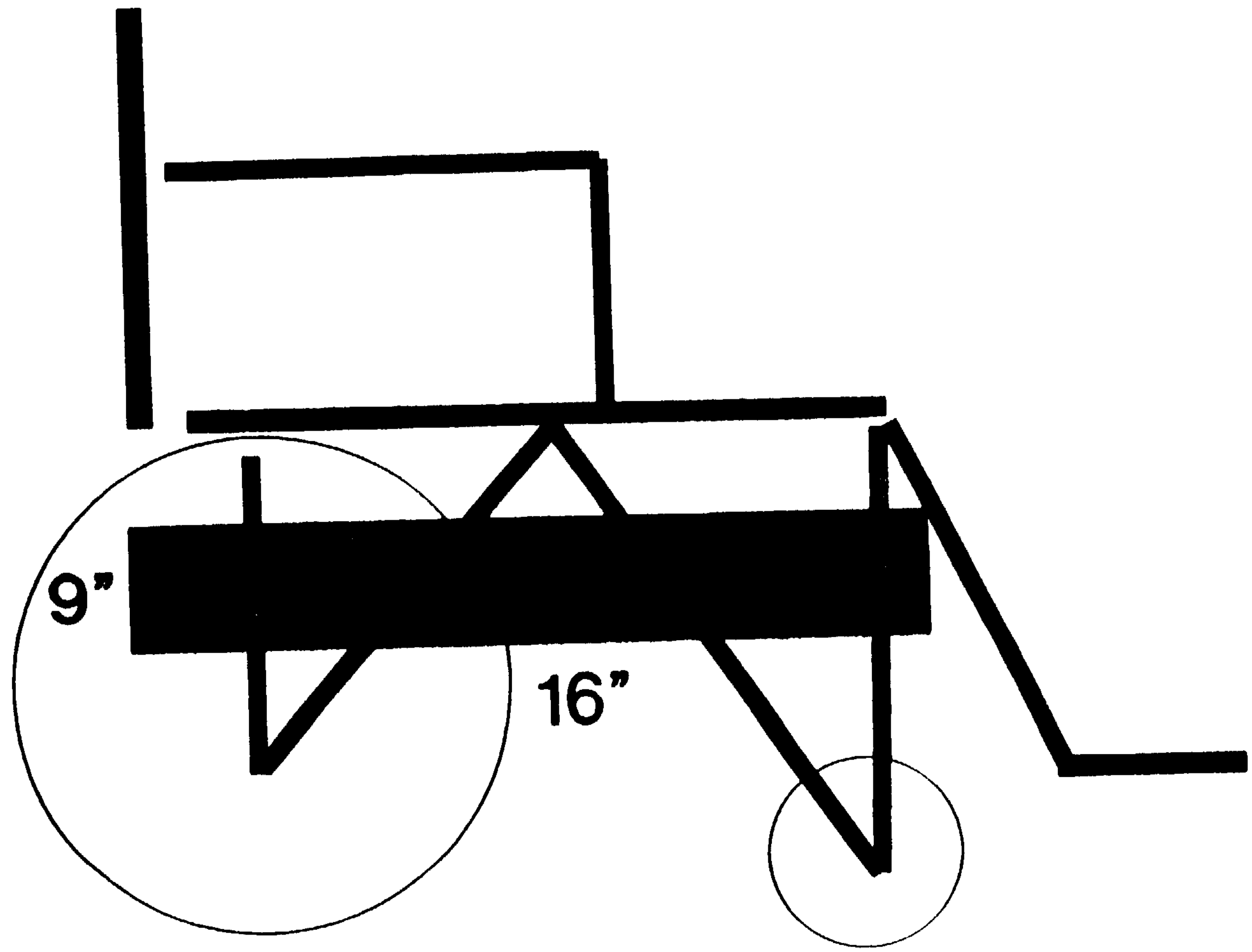


FIGURE 2
STAIR CLIMBING MECHANISM



GAS GENERATOR SYSTEM
FIGURE 3



WHEELCHAIR SIZE REQUIREMENT
FIGURE 4

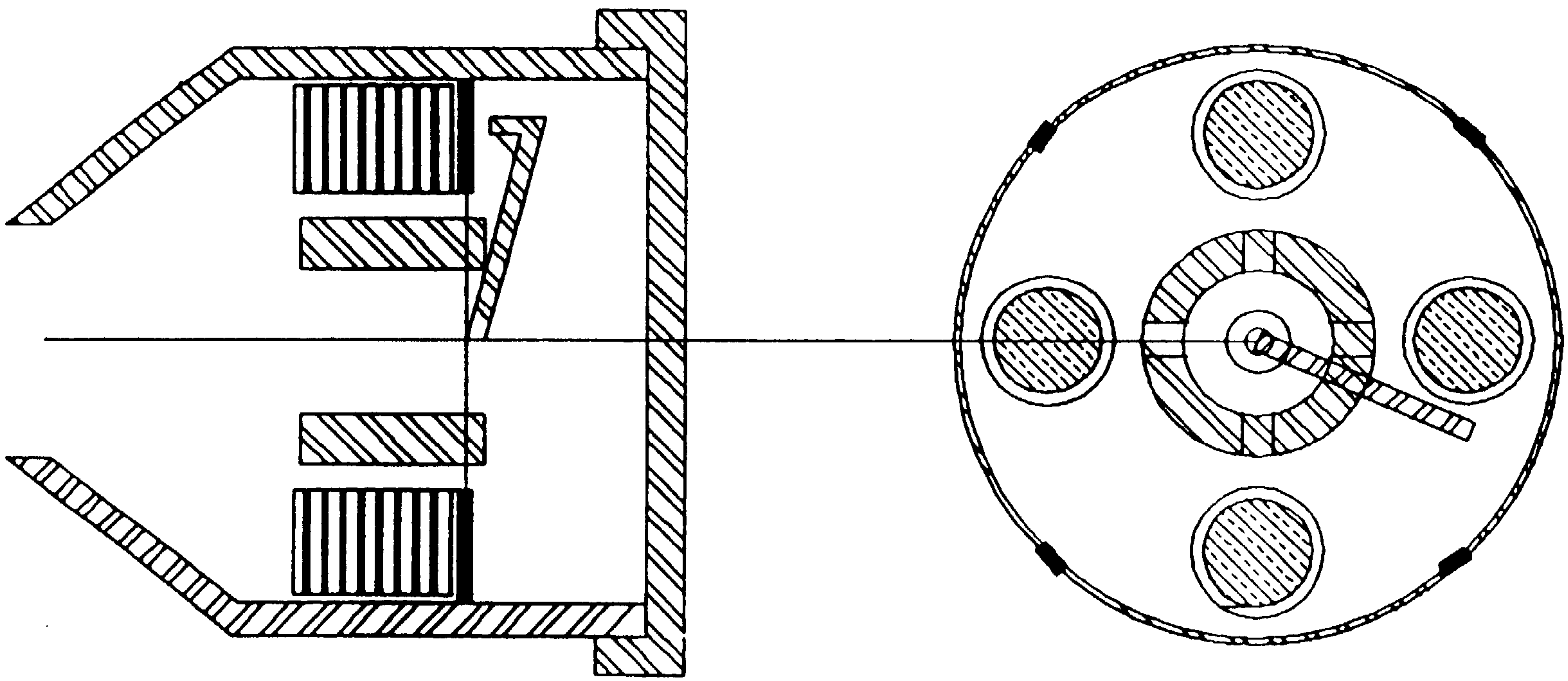
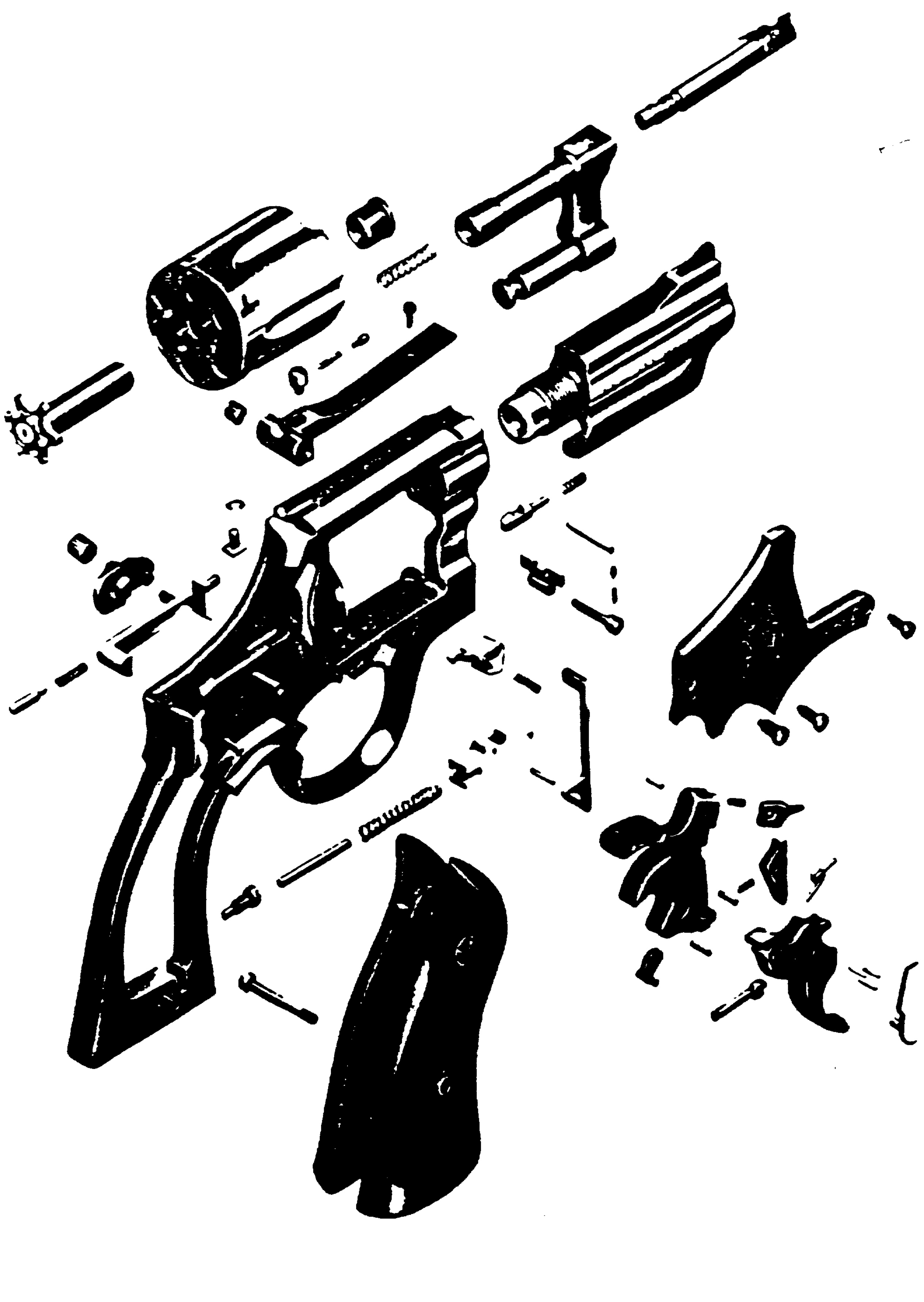


FIGURE 5
ROTATING FIRING MECHANISM HEAD



SMITH AND WESSON REVOLVER

FIGURE 6

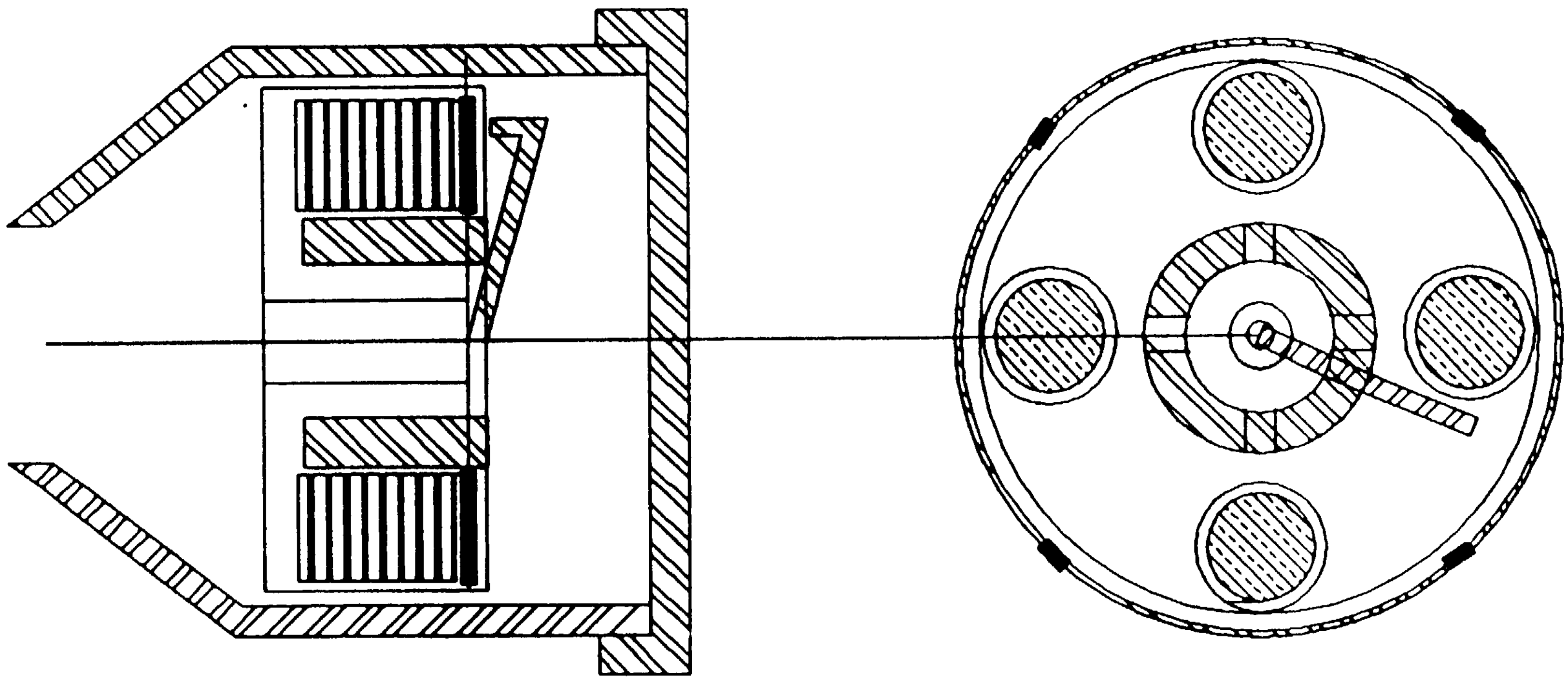


FIGURE 7
ROTATING FIRING MECHANISM CHAMBER

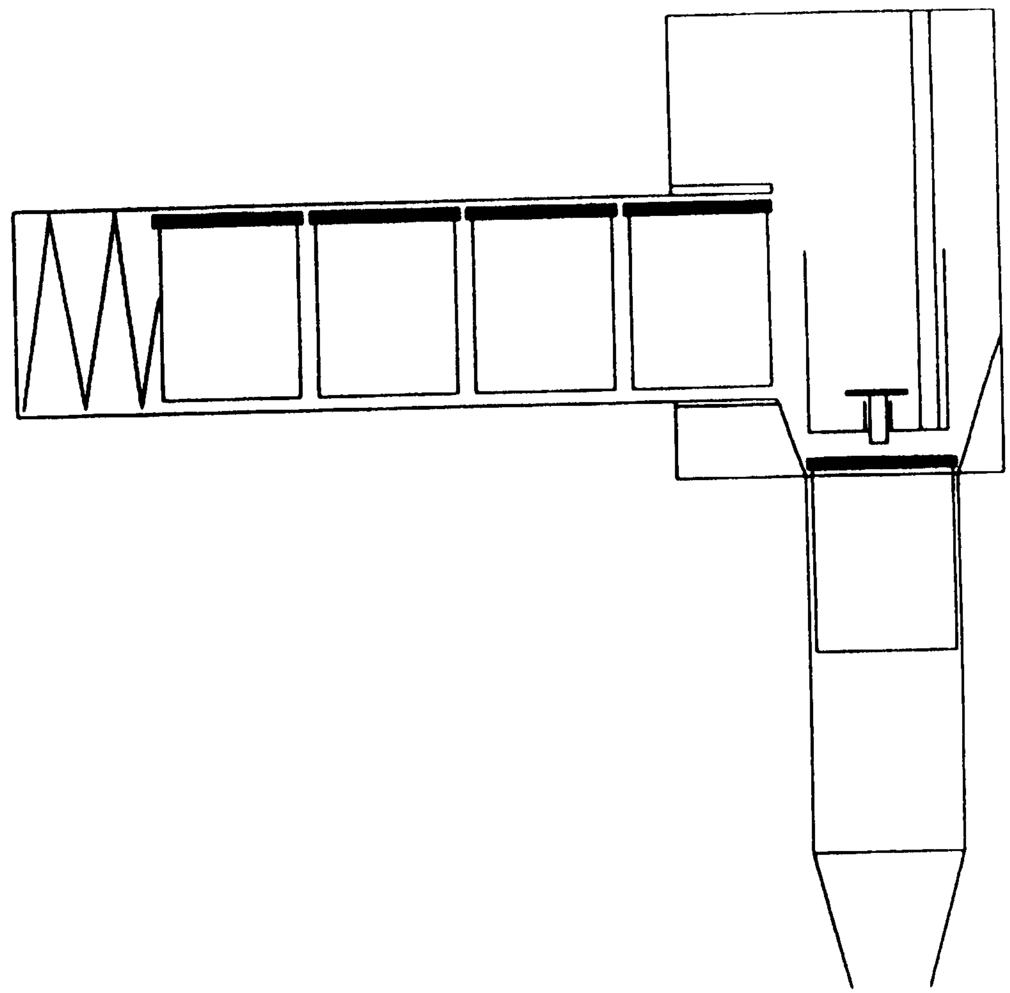


FIGURE 8
AUTOMATIC ARRANGEMENT WITH CLIP

FIGURE 9

SMITH AND WESSON MODEL 59

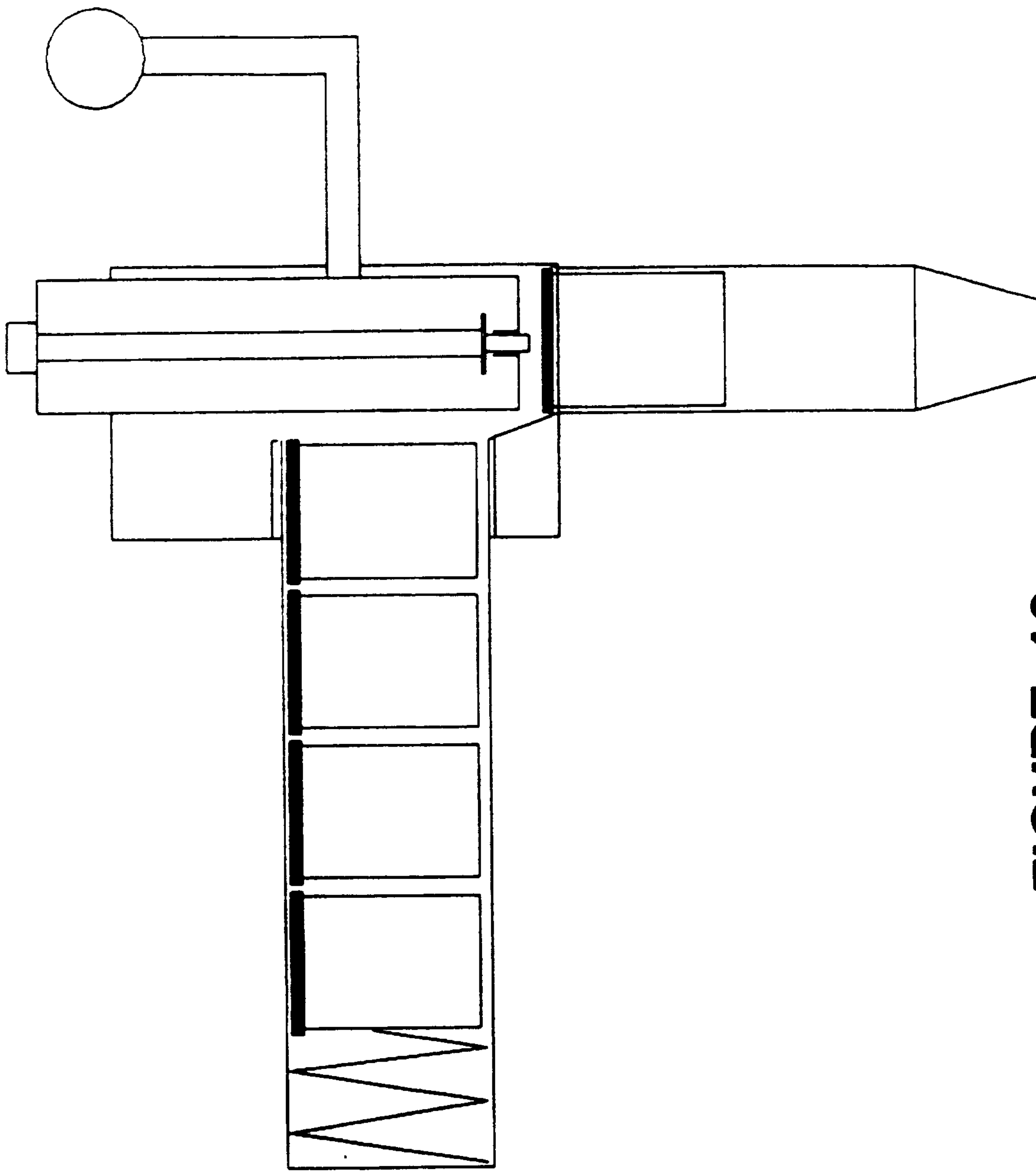


FIGURE 10
BOLT ACTION

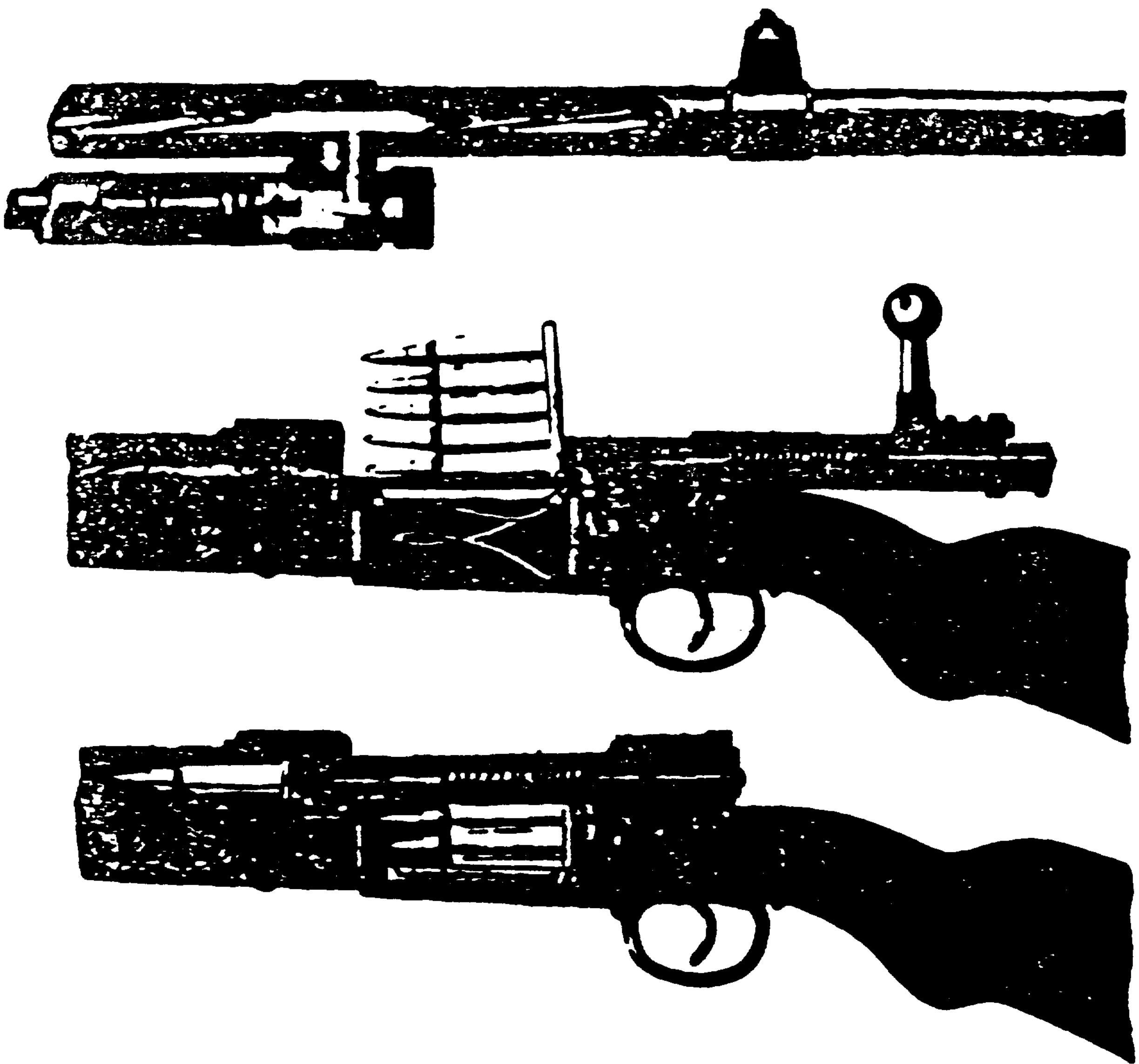
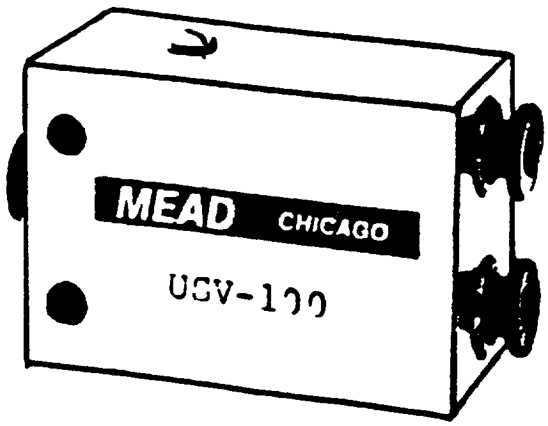


FIGURE 11

MAUSER KAR 98K

DIRECTIONAL CONTROL VALVE



USV-100

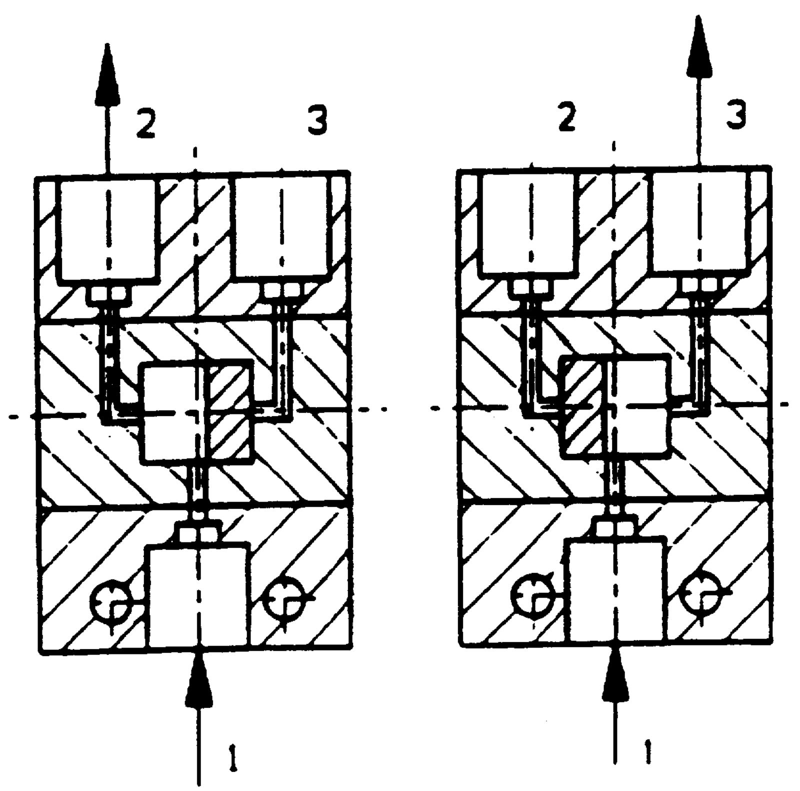


FIGURE 12

SODIUM AZIDE CARTRIDGE

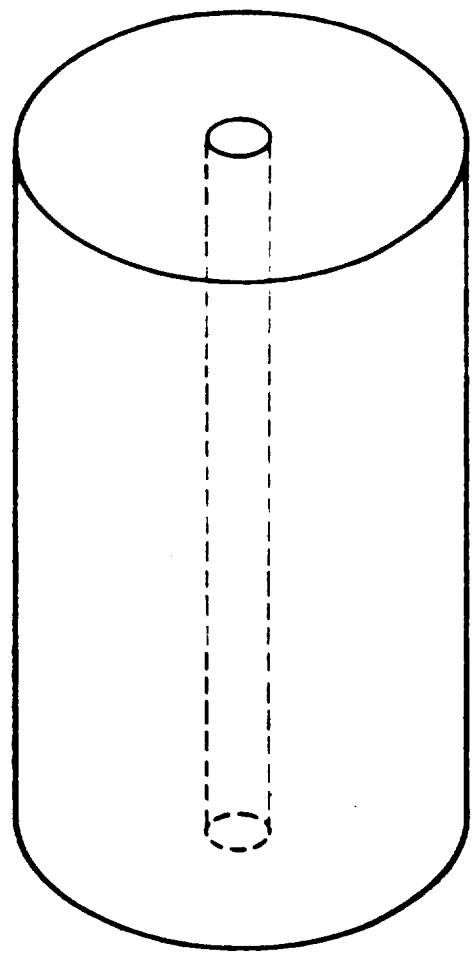


FIGURE 13

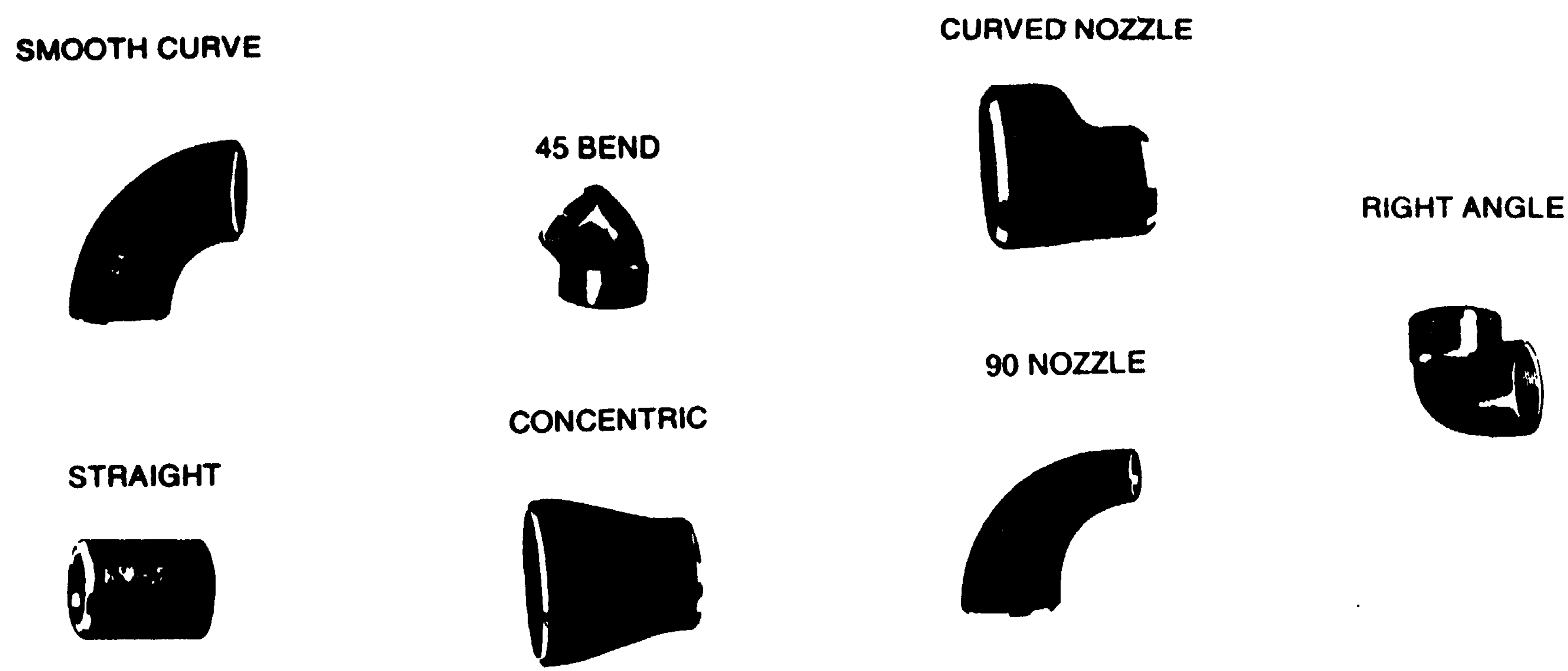


FIGURE 14
GAS GENERATOR BODY SHAPES

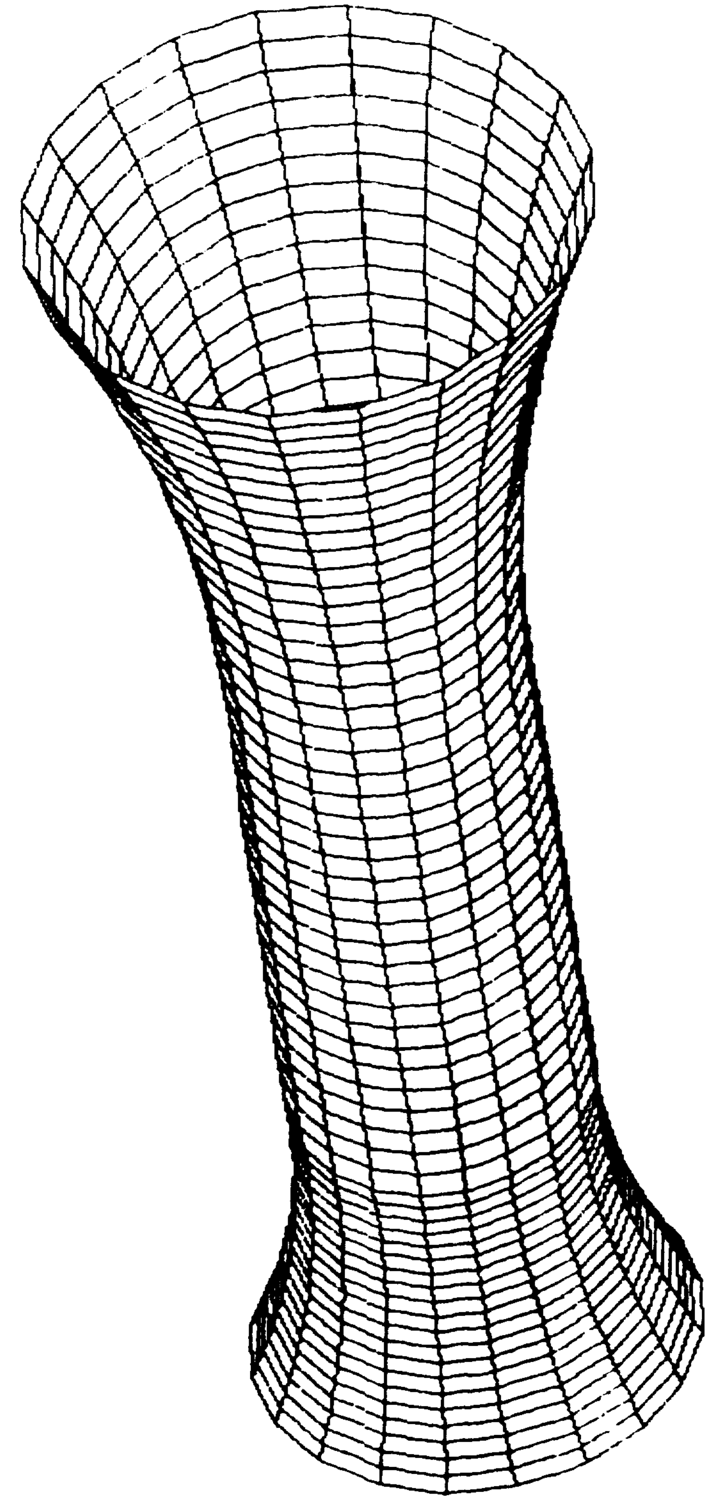


FIGURE 15
VENTURI

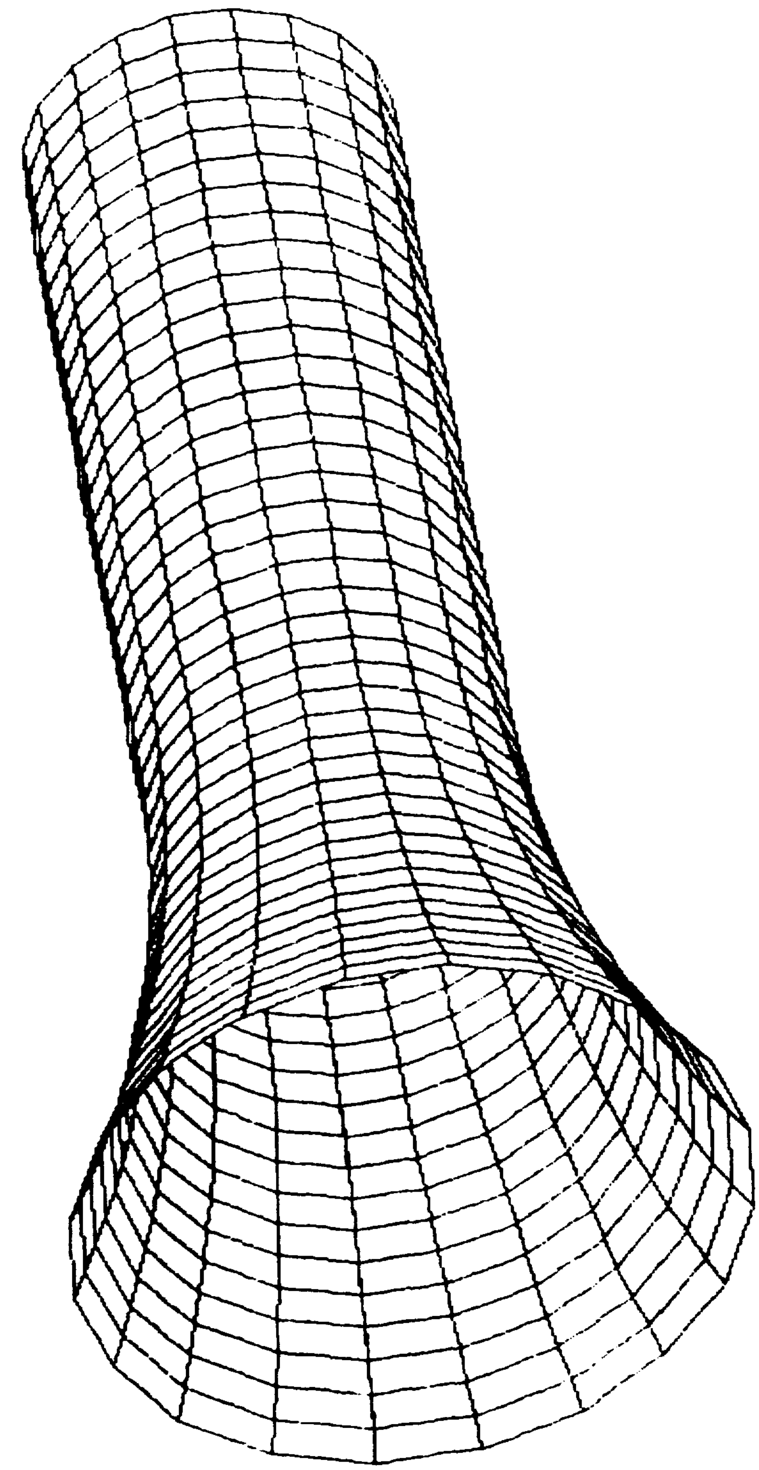


FIGURE 16
NOZZLE

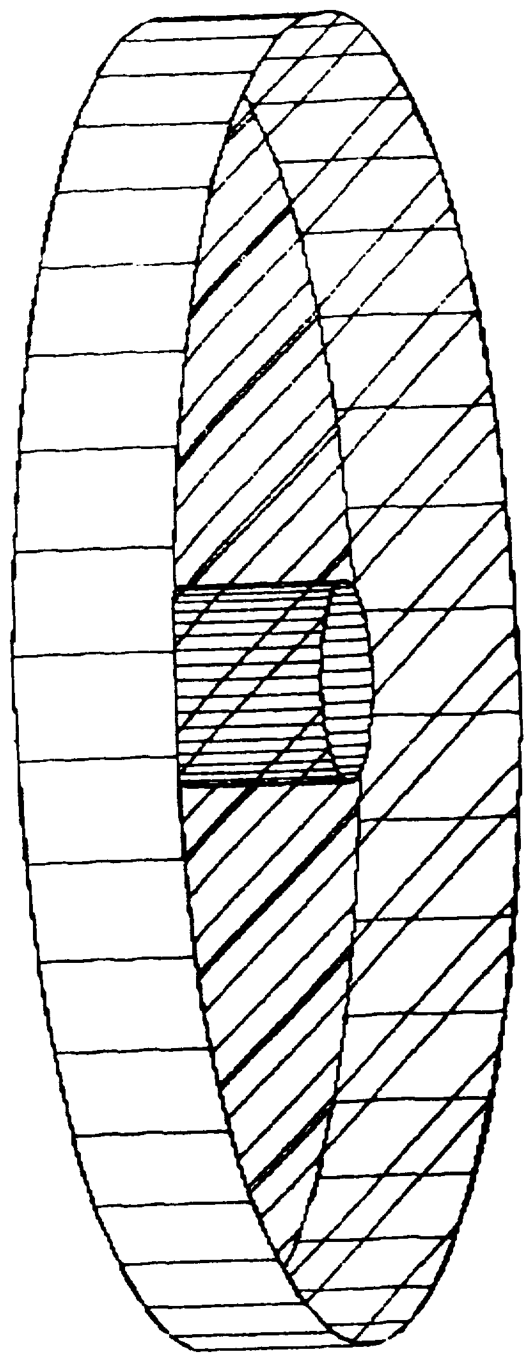


FIGURE 17
ORIFICE

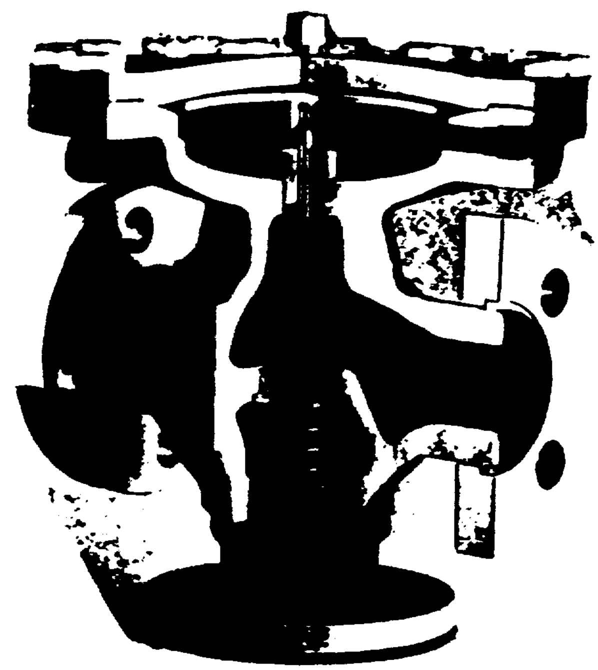


FIGURE 18
REDUCING VALVE

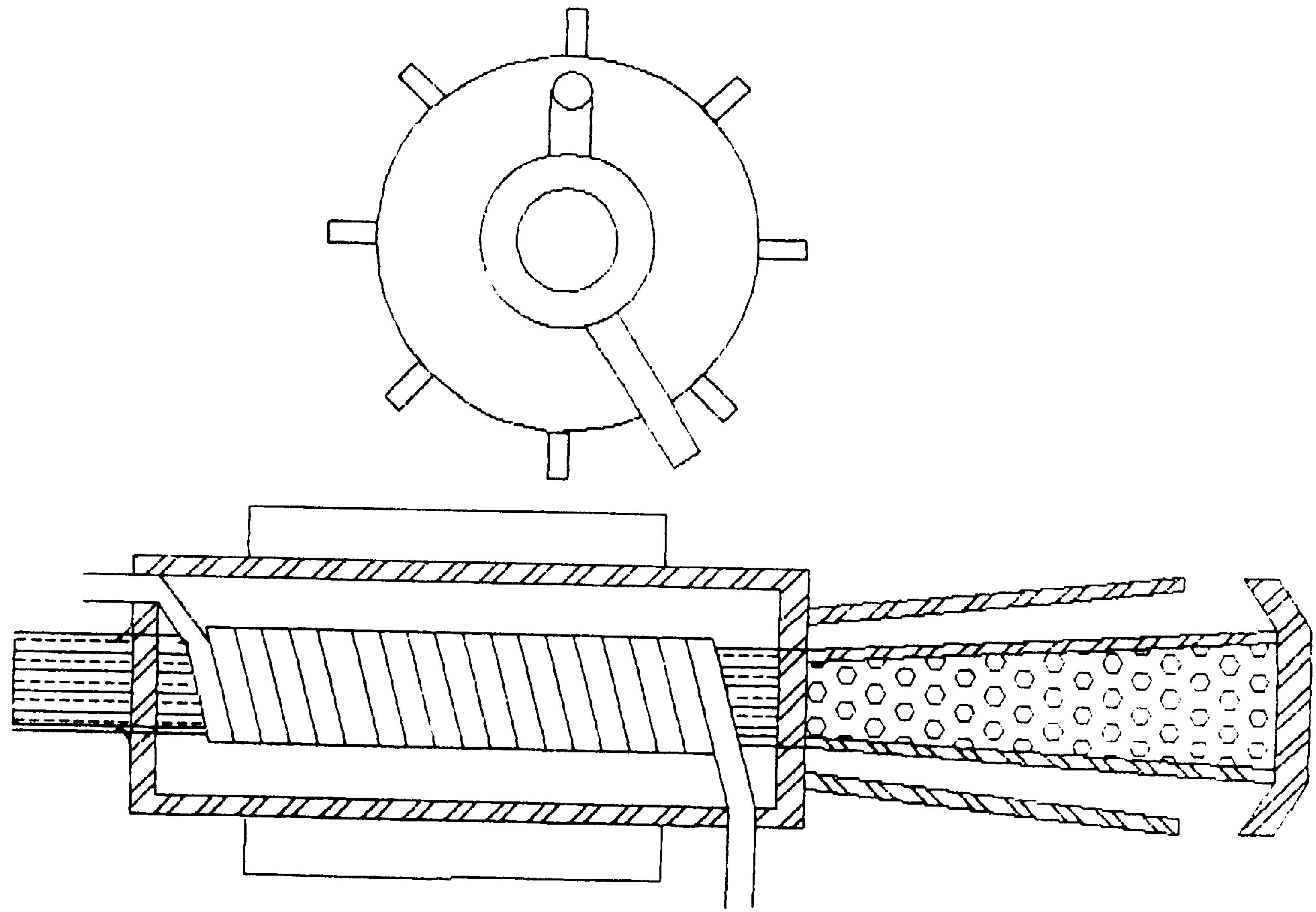
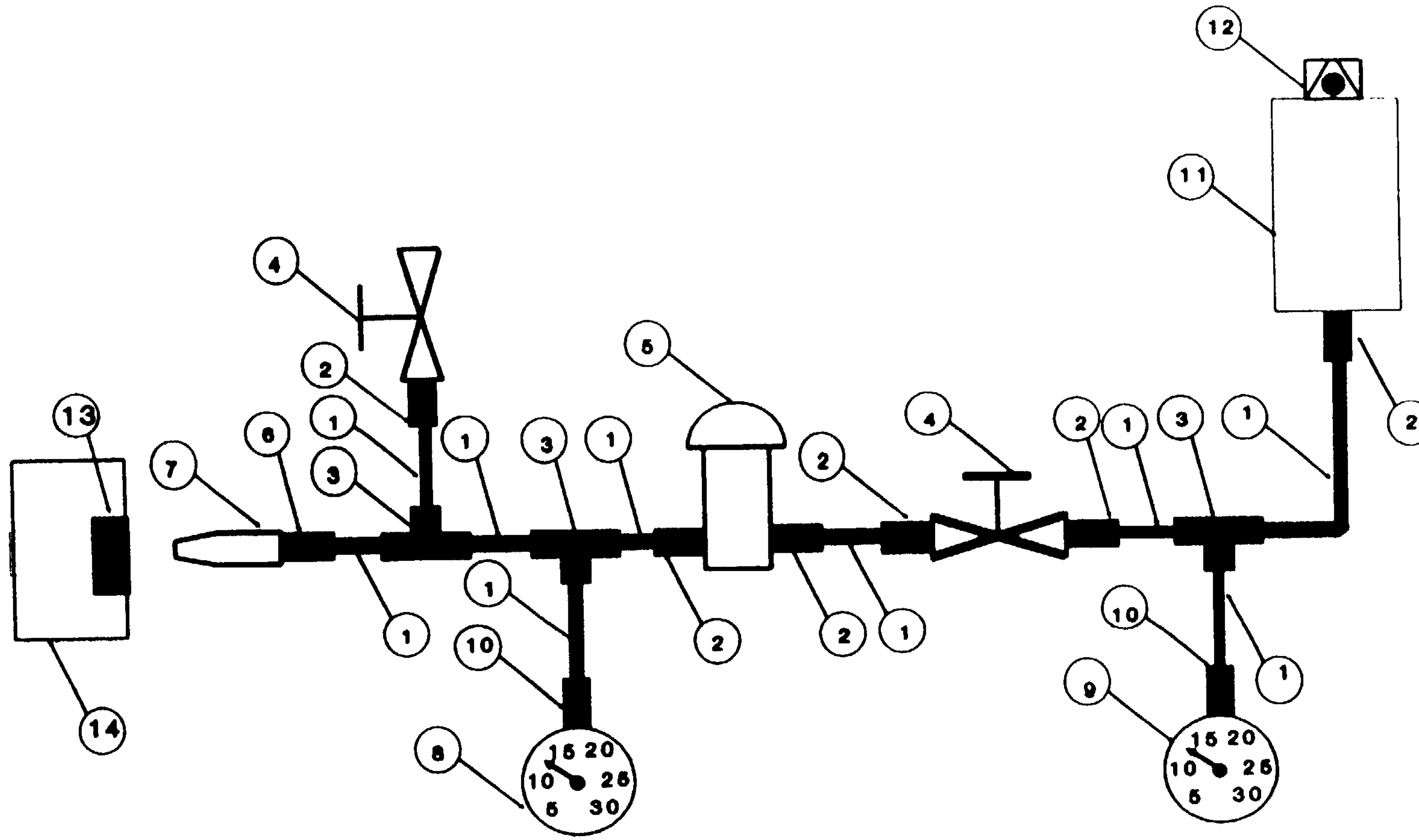
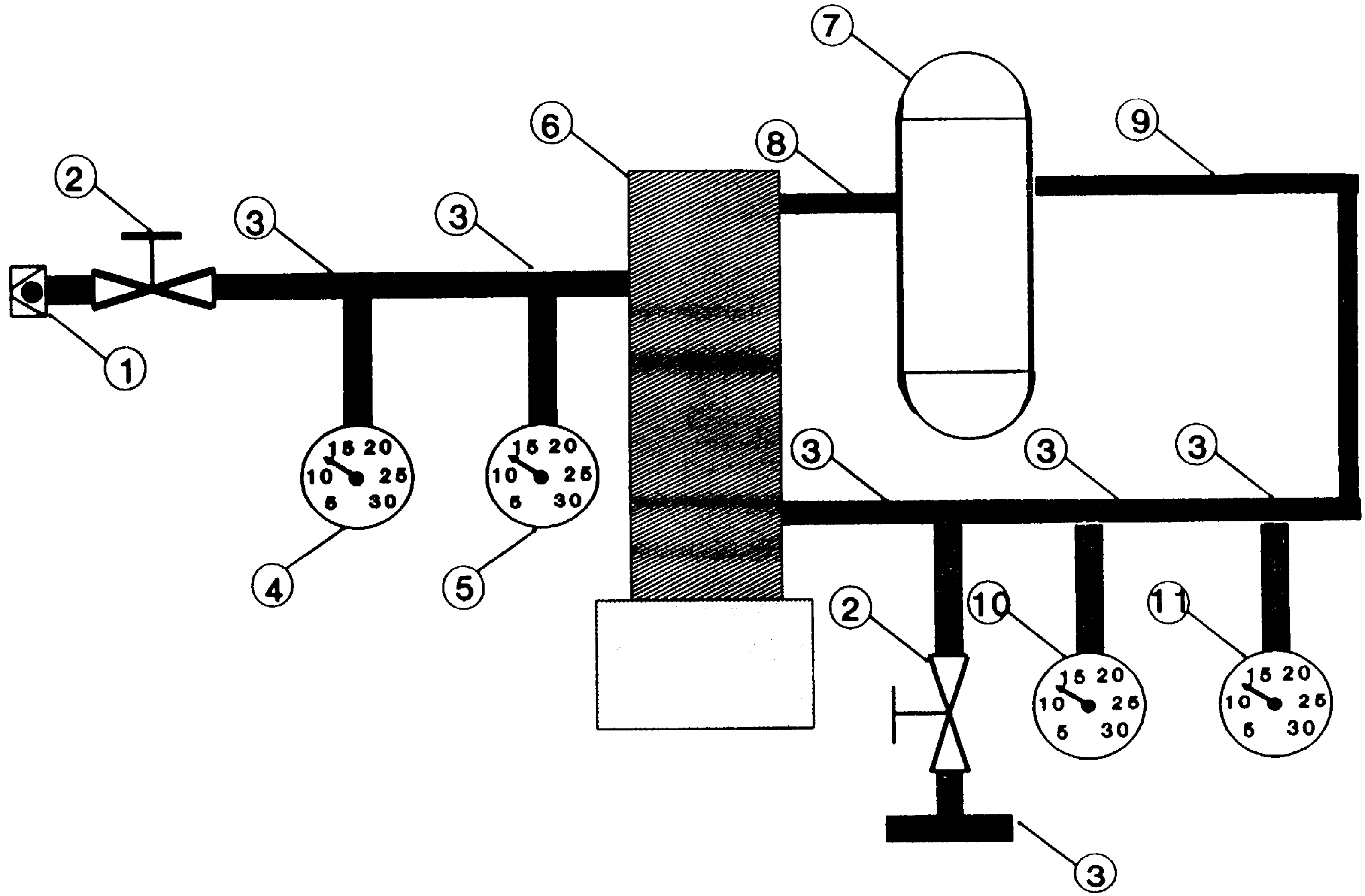


FIGURE 19
MUFFLER / HEAT EXCHANGER



TEST # 1 - PERCUSSION ACTUATOR

FIGURE 20



TEST # 2 - INTENSIFIER PERFORMANCE

FIGURE 21

TEST SETUP #6

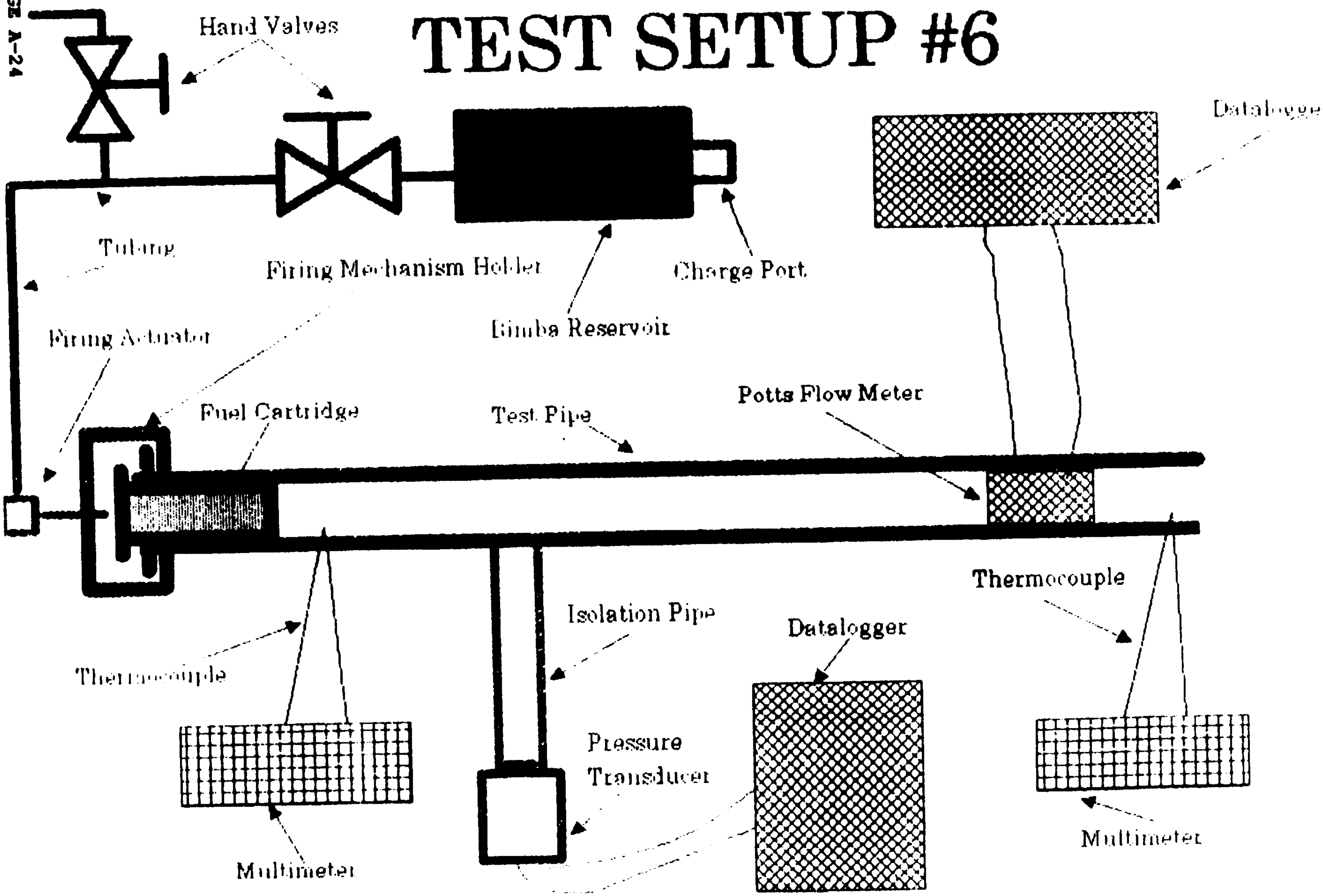


FIGURE 22

TEST #9 SCHEMATIC

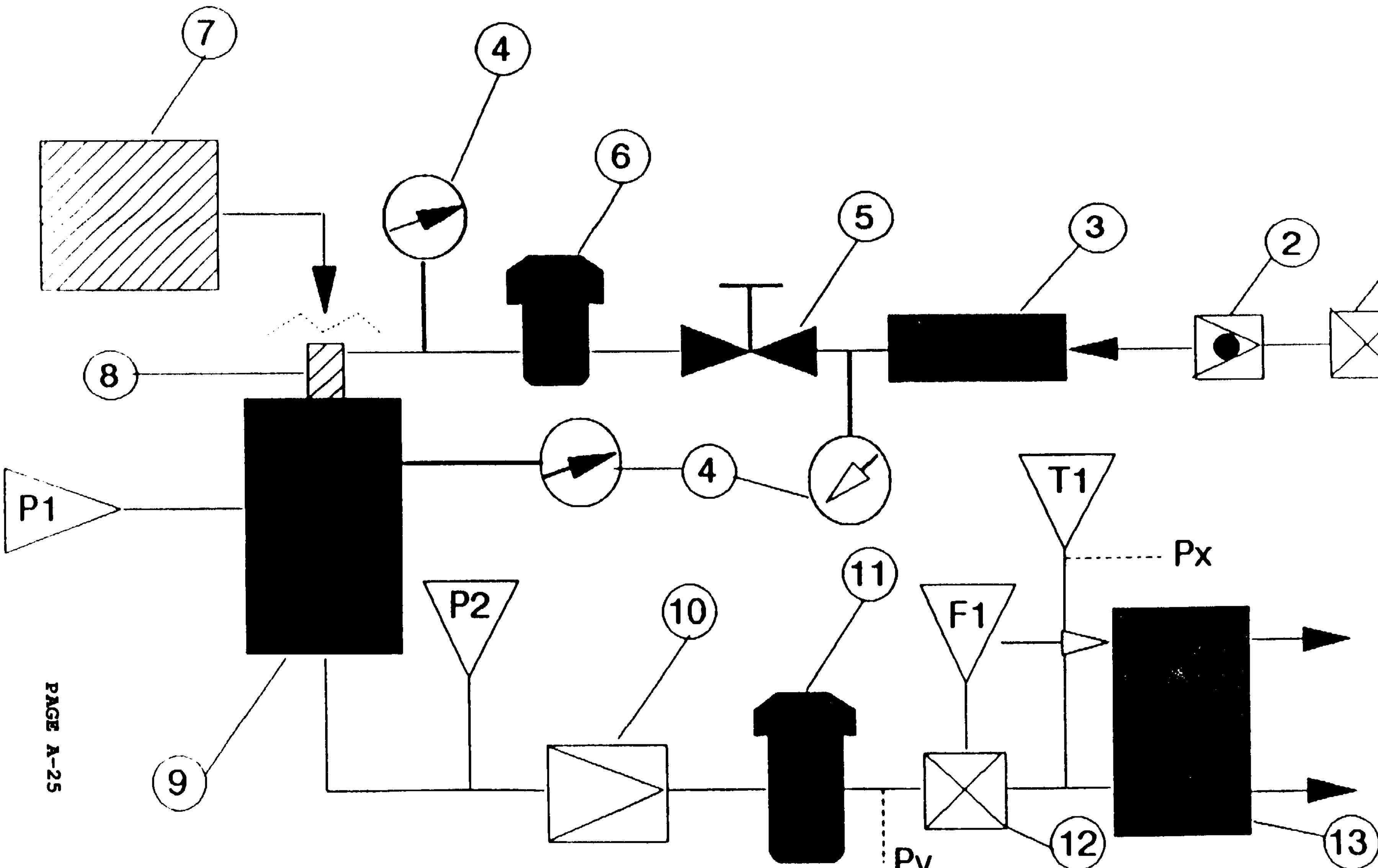


FIGURE 23

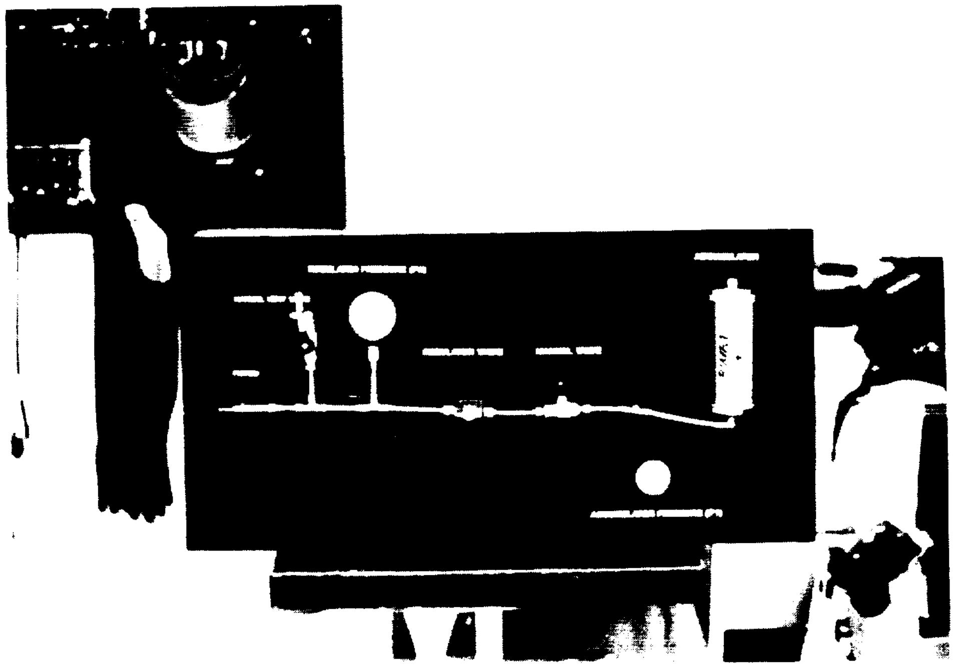


FIGURE 24
FIRING MECHANISM SETUP

FIRING PIN MACHINING

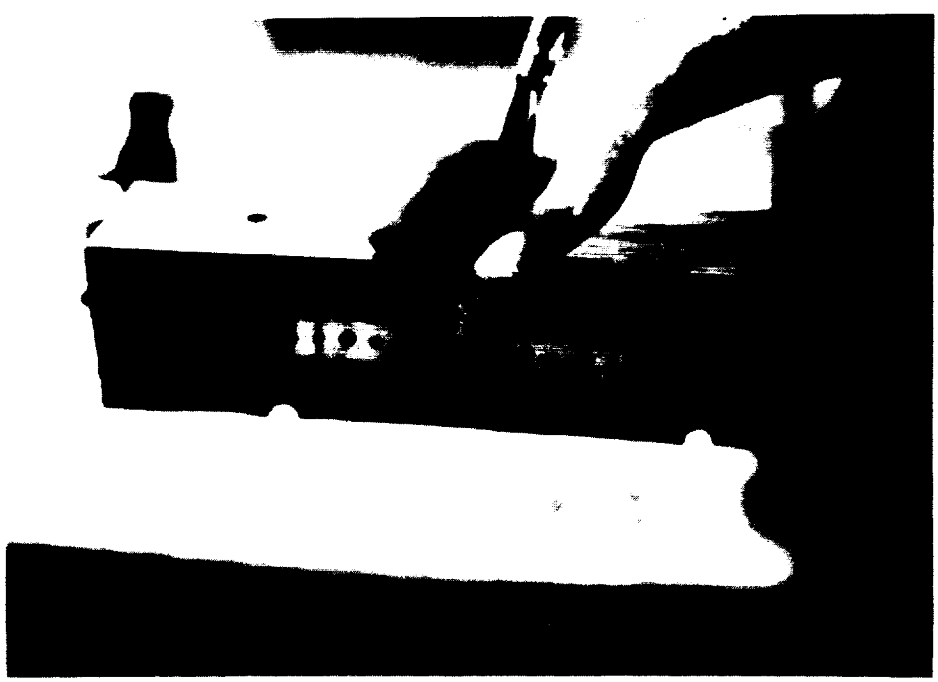


FIGURE 25

FIGURE 26
FIRING SEQUENCE UNACTUATED

FIRING SEQUENCE ACTUATED

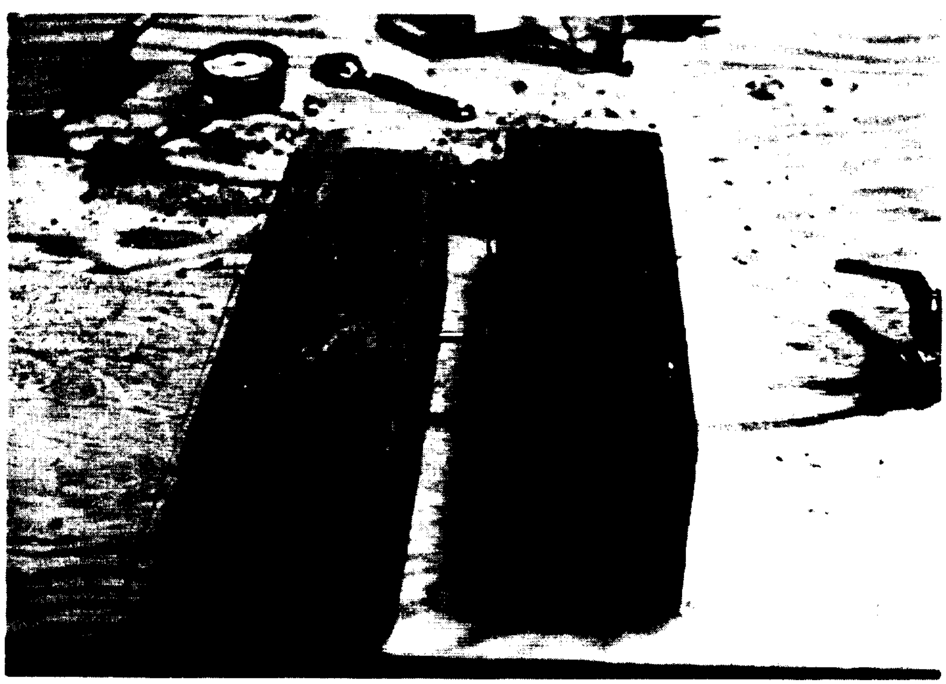


FIGURE 27

FIGURE 28
FIRING SETUP WITH REGULATOR

FIRING SETUP WITHOUT REGULATOR

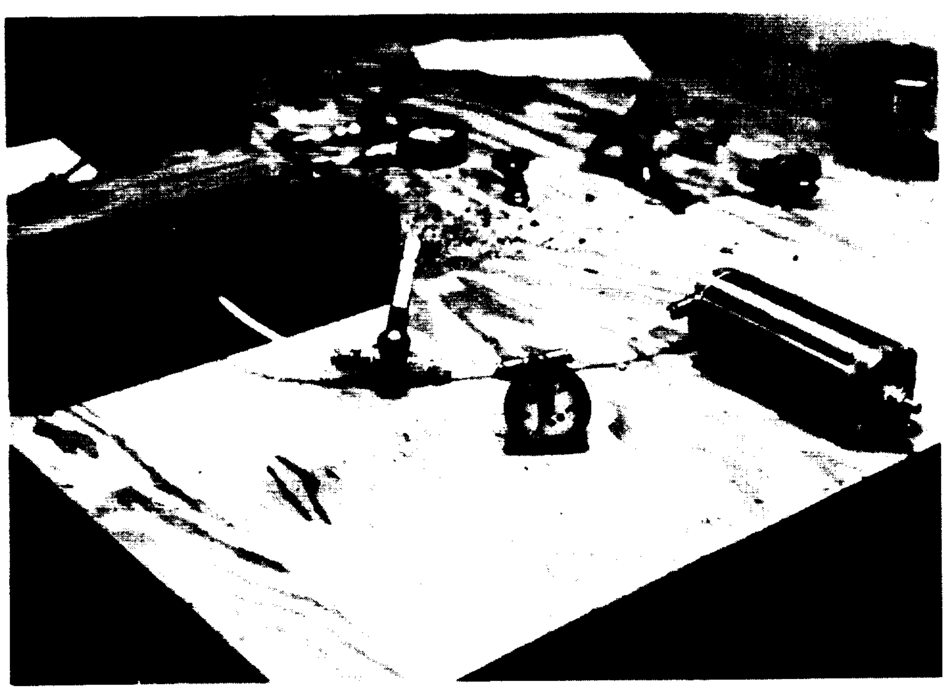


FIGURE 29

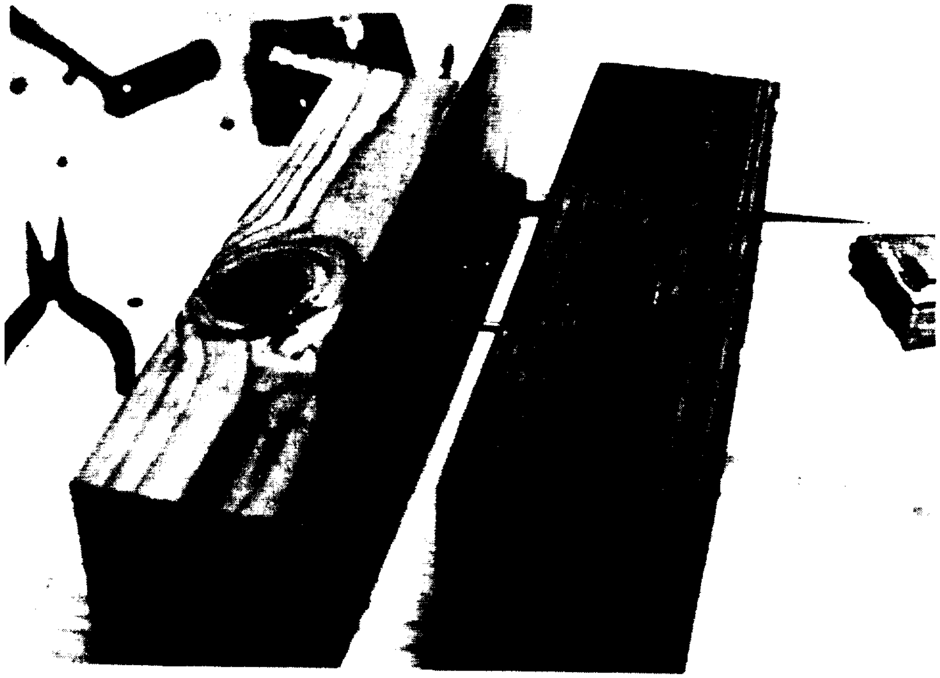


FIGURE 30
FIRING MECHANISM WITH STEEL SUPPORT

FIRING MECHANISM PRIMER HOLDER

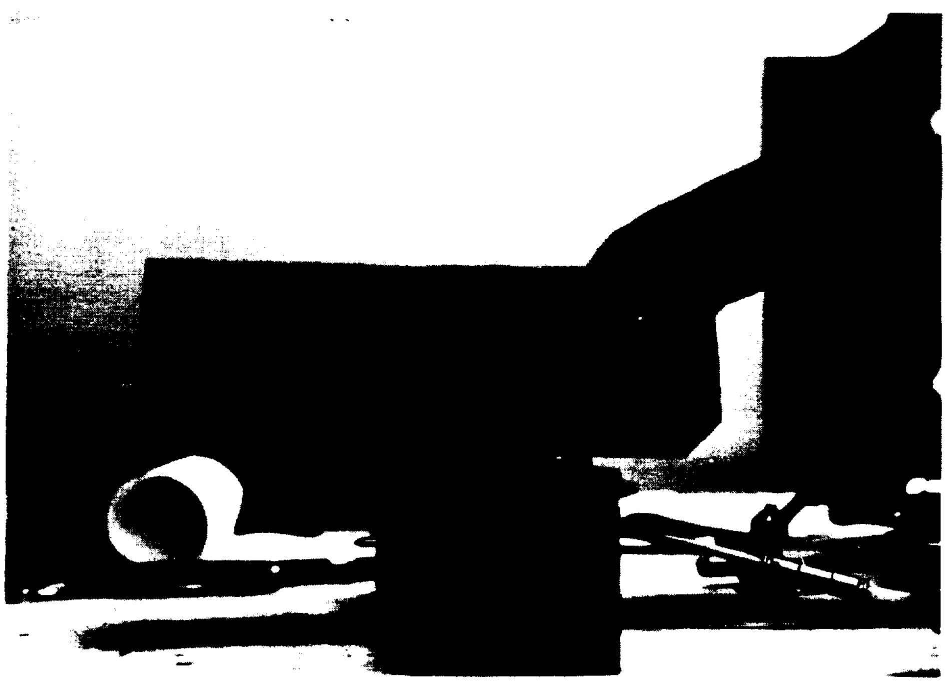


FIGURE 31

USED PRIMERS

FIGURE 32

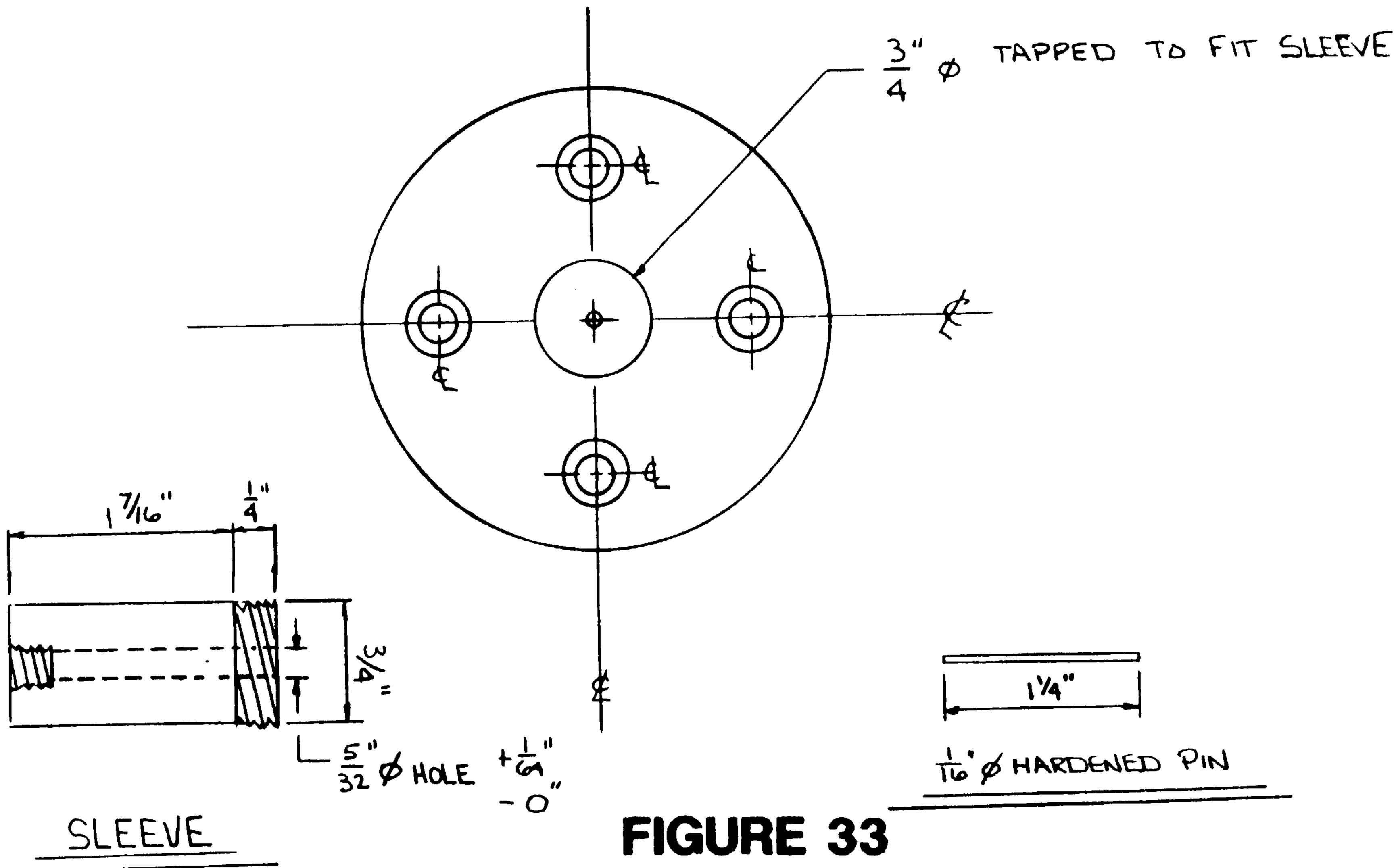
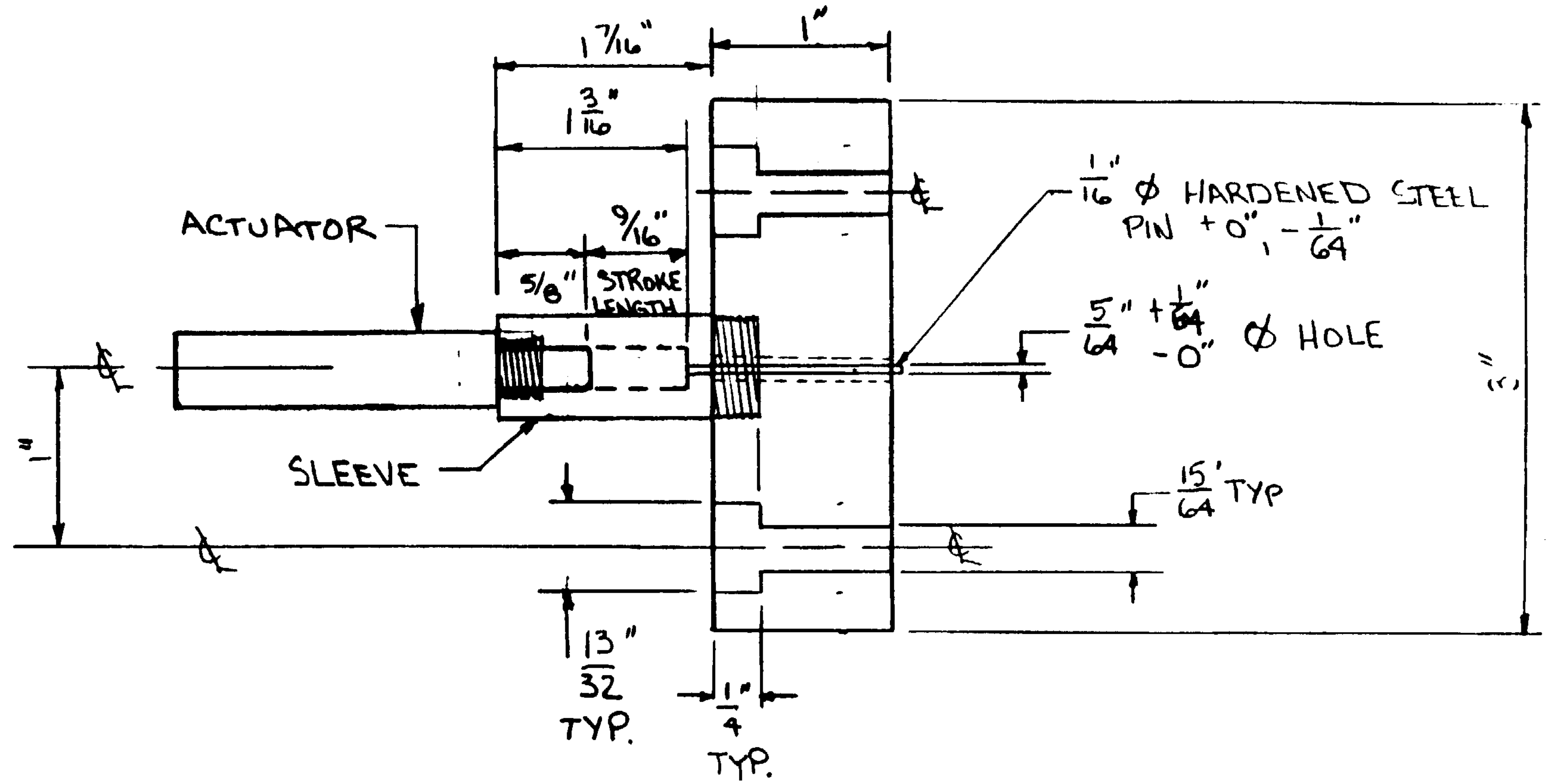


FIGURE 33
MODIFIED FIRING HEAD
(SIDE VIEW)



NOTES:
ALL ALLOWANCES ARE ± 1/64" UNLESS OTHERWISE SPECIFIED
ALL MATERIAL IS ALUMINUM EXCEPT HARDENED (TOOL STEEL) PIN

FIGURE 34
MODIFIED FIRING HEAD
(PLAN VIEW)

SCALE 1" = 1"

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

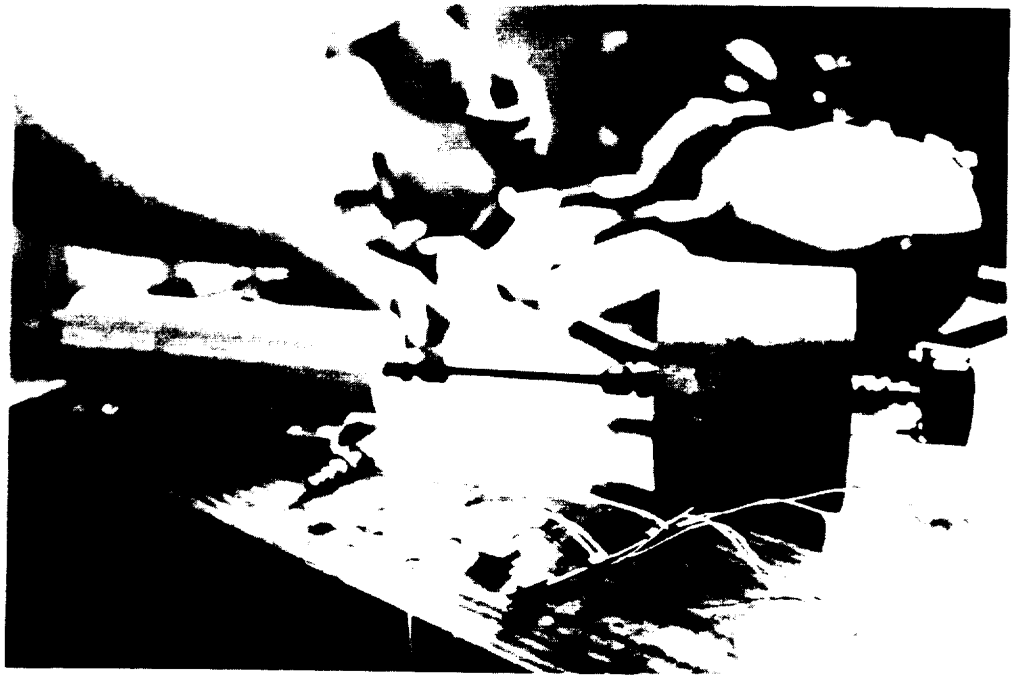


FIGURE 35
FIRING MECHANISM WITH 116 CID ACCUMULATOR

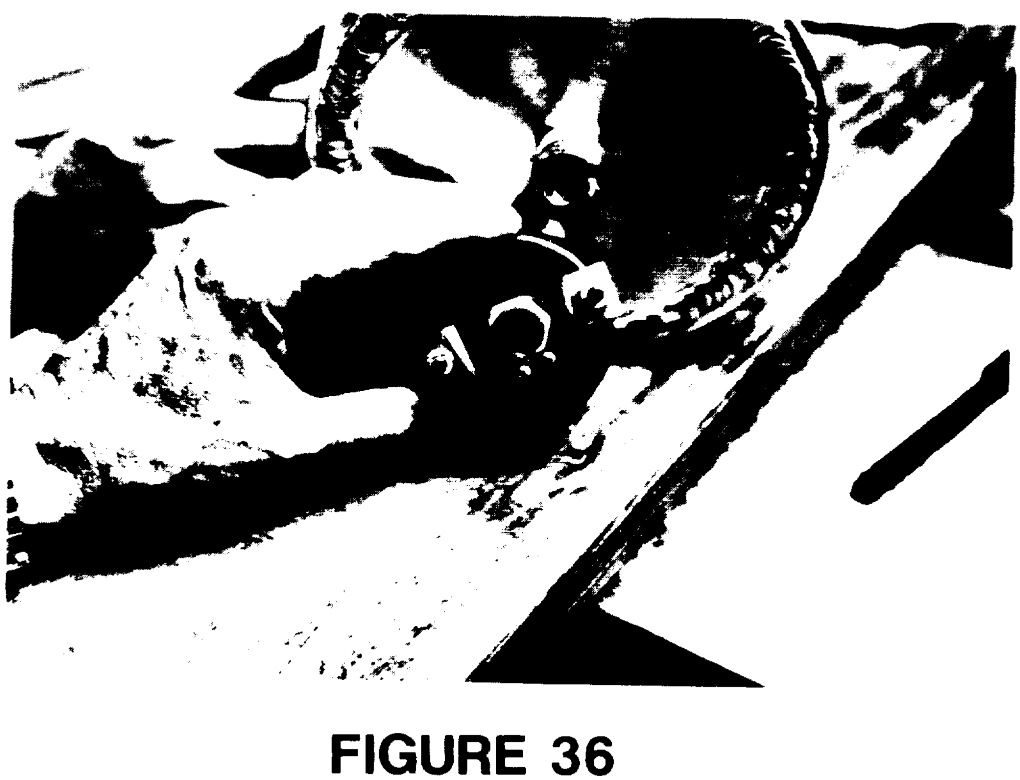
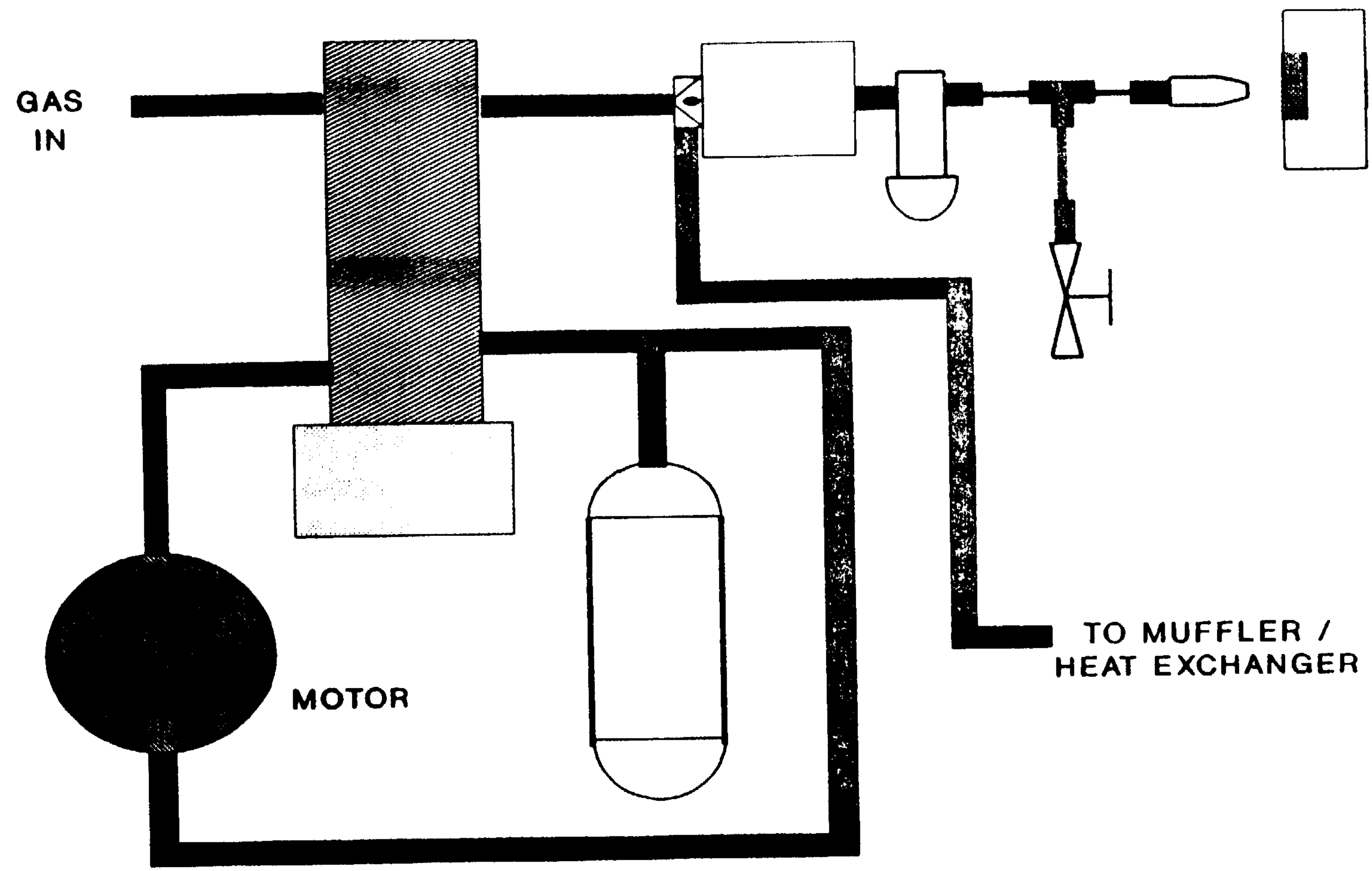
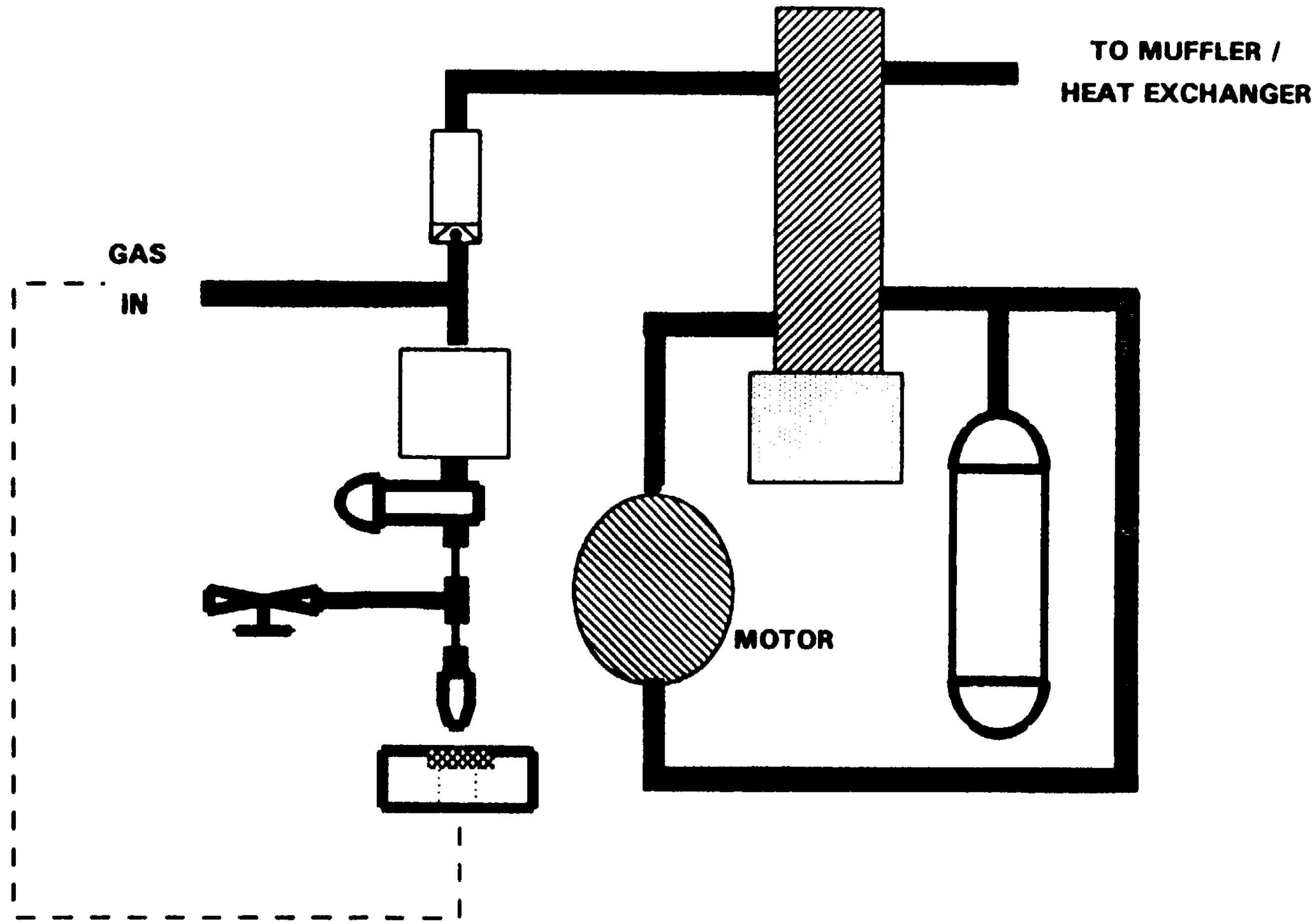


FIGURE 36
SOLID RESIDUE BUILDUP IN PRESSURE GAUGE



IGNITION PISTON ACCUMULATOR RECHARGE SYSTEM

FIGURE 37



IGNITION PISTON ACCUMULATOR RECHARGE SYSTEM

FIGURE 38

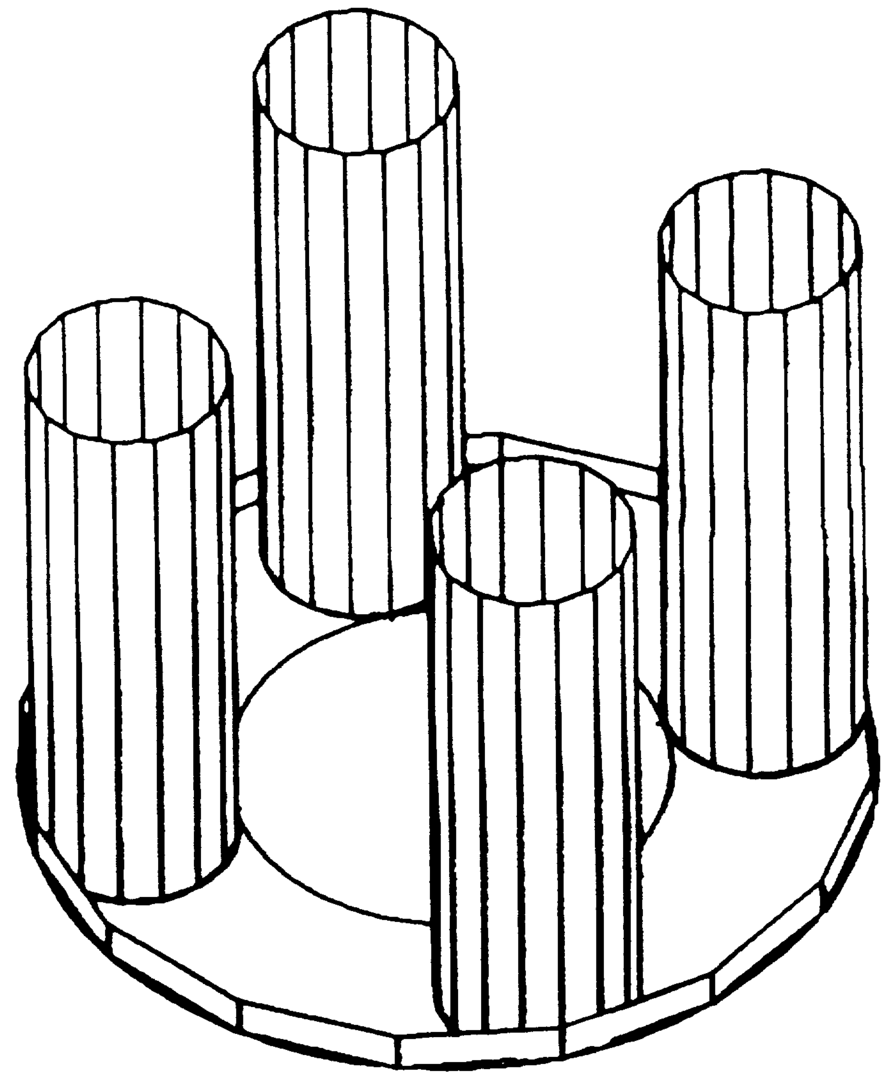


FIGURE 39
FOUR CARTRIDGE DISK

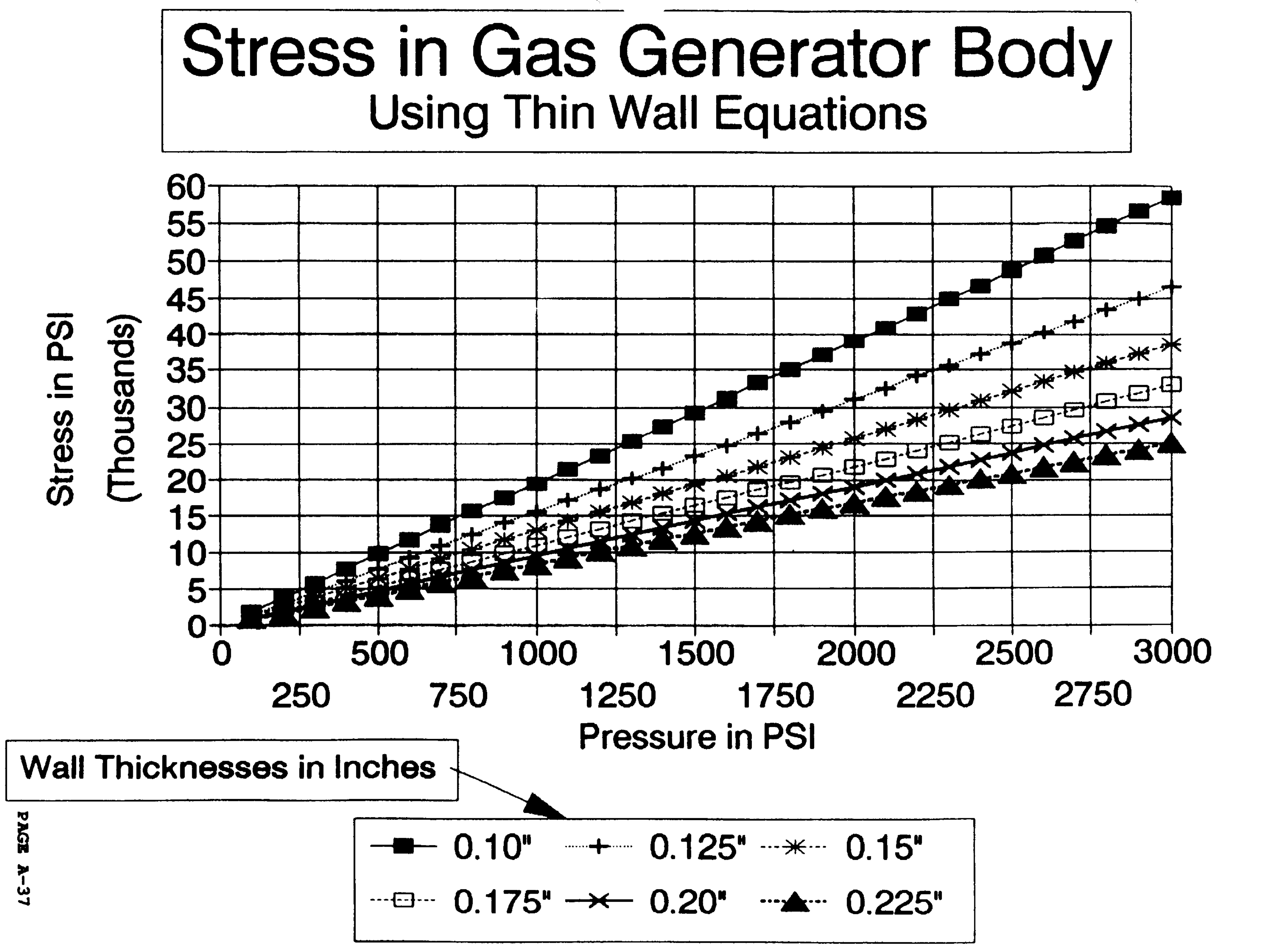

Stress in Gas Generator Body
Using Thin Wall Equations
Stress in PSI
(Thousands)
60
55
50
45
40
35
30
25
20
15
10
5
0
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
Pressure in PSI
Wall Thicknesses in Inches
0.10"
0.125"
0.15"
0.175"
0.20"
0.225"

FIGURE 40

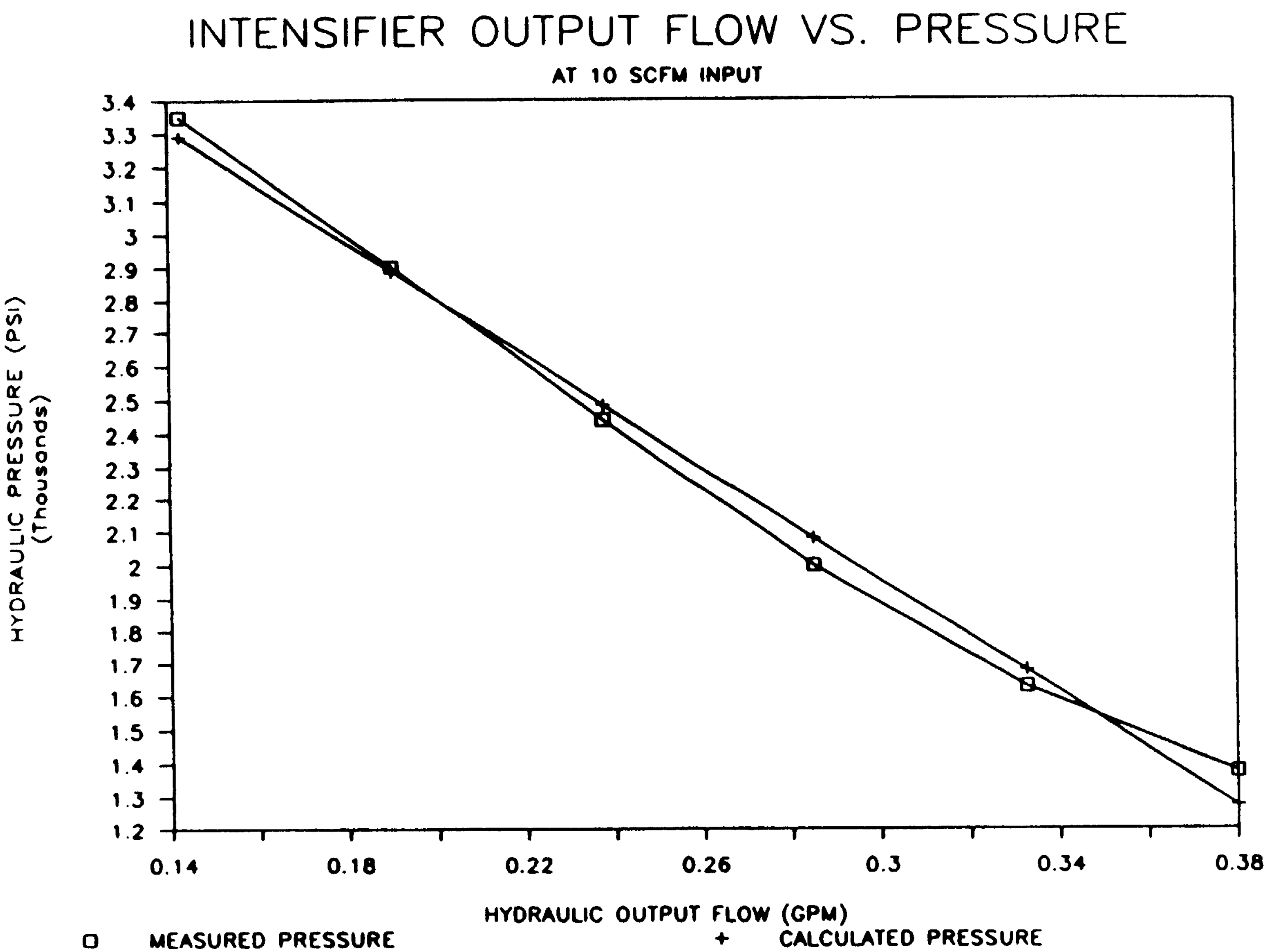
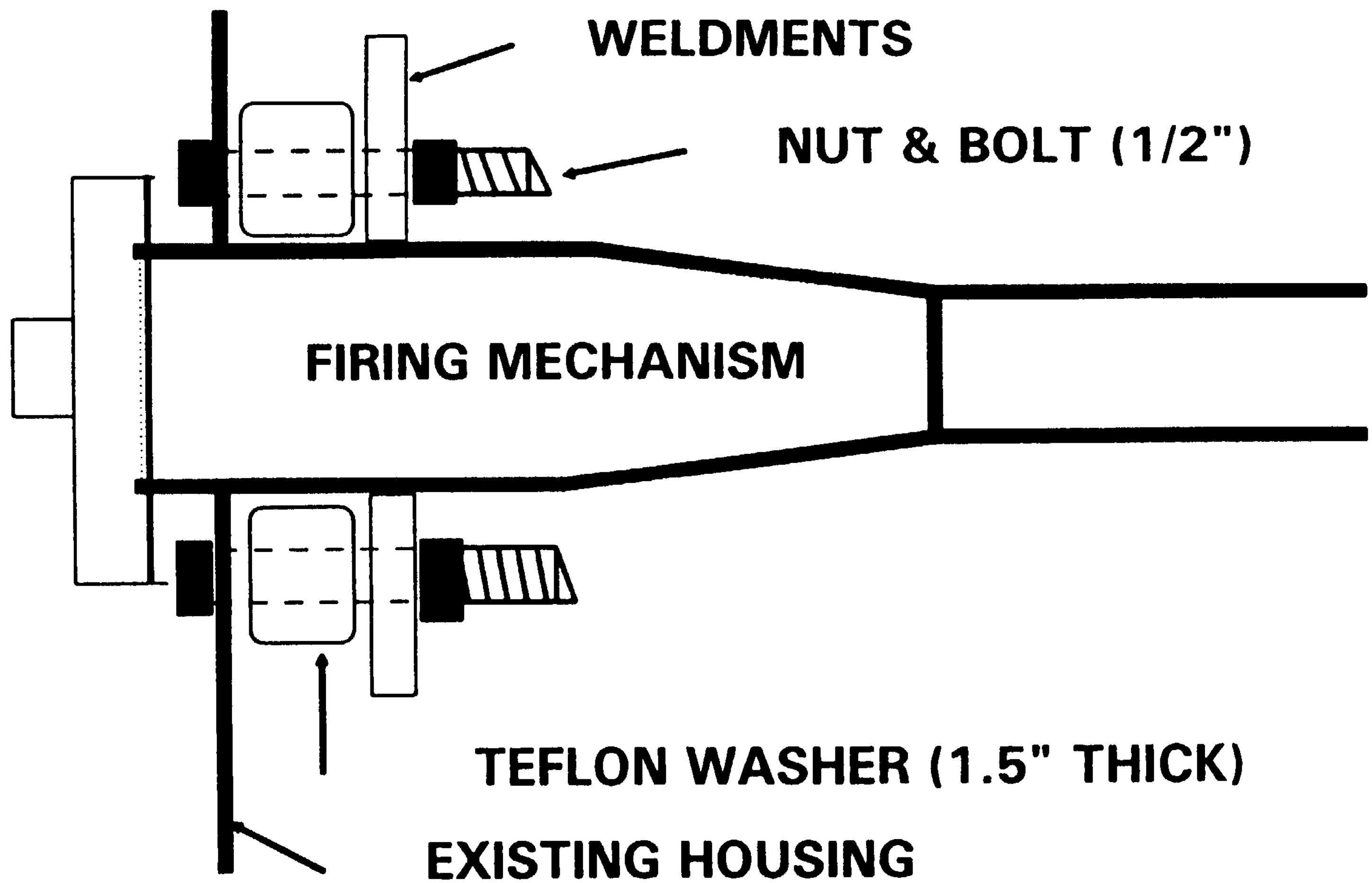

INTENSIFIER OUTPUT FLOW VS. PRESSURE
AT 10 SCFM INPUT
HYDRAULIC PRESSURE (PSI)
(Thousands)
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
0.14
0.18
0.22
0.26
0.3
0.34
0.38
HYDRAULIC OUTPUT FLOW (GPM)
MEASURED PRESSURE
CALCULATED PRESSURE

FIGURE 41



FIRING MECHANISM ATTACHMENT

FIGURE 42

KING STREET FACILITY
TEST SETUP

FIGURE 43

APPENDIX B

TABLES

TABLE 1

propellant data sheet

TALLEY DEFENSE SYSTEMS | talley industries

TAL-1101 MOD. 1.40

Description: Sodium Azide/Copper Oxide

BALLISTIC PROPERTIES:

Burning Rate Equation (80°F) .... $r_b = 1.40\ (Pc/1000)^{.48}$
Area Ratio Equation (calc, 80°F) .... $k_n = 119\ (Pc/1000)^{.52}$
Temperature Sensitivity (%/°F)
Temperature Range -30 to +165°F $\pi_k = 0.30$

THEORETICAL PROPERTIES: ①

Flame Temperature (°F) 2026
Characteristic Exhaust Velocity (C*, ft/sec) 2165
Specific Impulse (1000 psia in std. atmosphere, lbf-sec/lbm) exit 112.6
Molecular Weight, Gas (avg) 28.03
Ratio of Specific Heats (γ) 1.112
Enthalpy (cal/gram) ② .... -136.9
Approximate Gas Composition (Mole %) Exhaust (1 Atm) % Solids

Gas %		Solids	
N_2	99.29	Cu	31.16
O_2	0.75	Na_2O	29.09

Molecular Weight Exhaust Gas 28.03

PHYSICAL PROPERTIES:

Form: Powder or Pressed Grain..........
Density (lb/in³, 80°F), Pressed Grain 0.089
Autoignition: > One hour at 700°F

ICC Classification ....Propellant Explosive, Solid, Class B

① *Shifting equilibrium calculations, chamber conditions except as noted.*

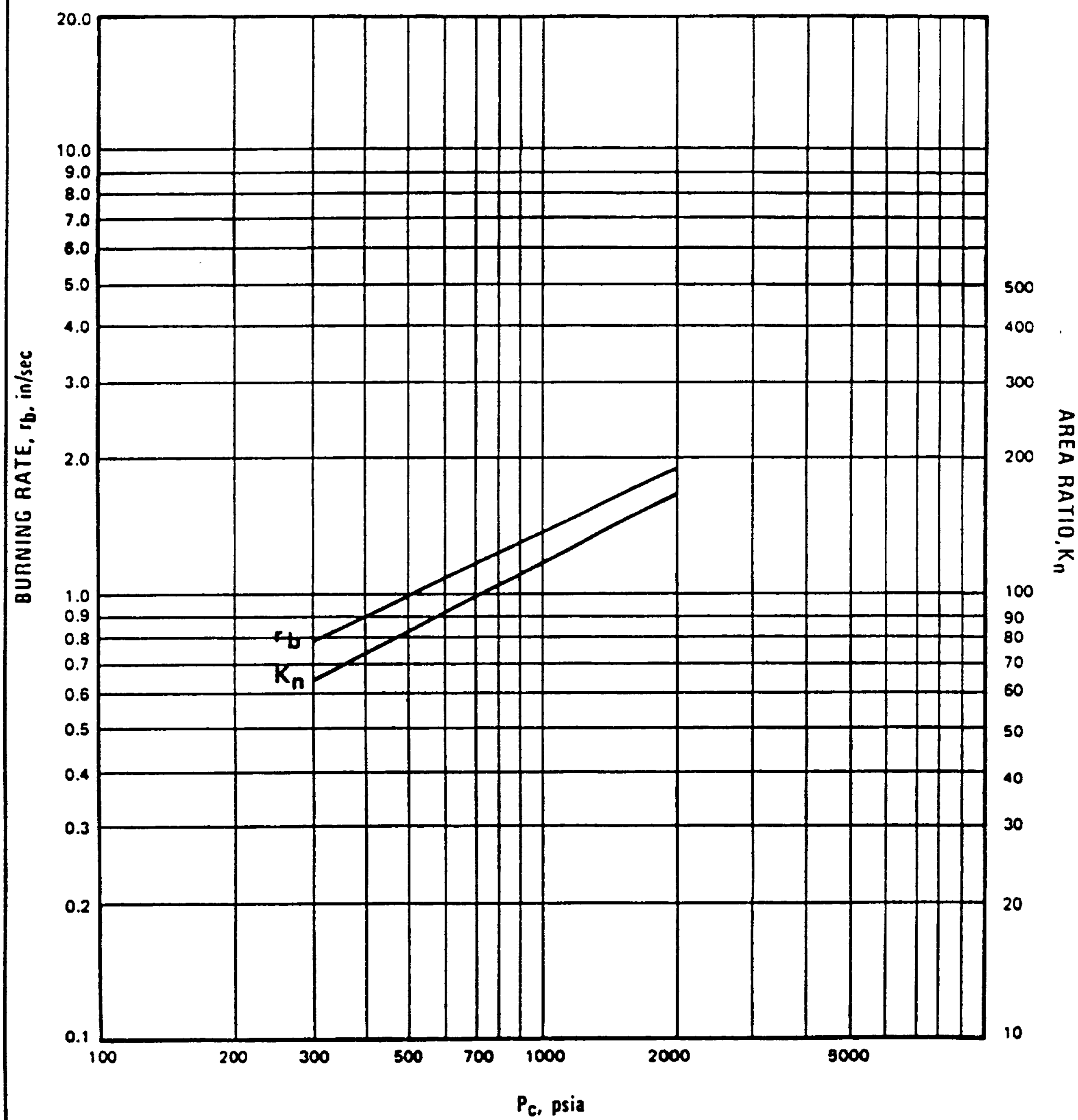
② *From NASA-LEWIS exhaust gas analysis program, Report Number NASA SP-273, NTIS Report Number N71-37775.*

June 1984

MORE TECHNICAL DATA ON REVERSE SIDE

TABLE 2

BURNING RATE AND AREA RATIO
VERSUS
CHAMBER PRESSURE
TAL-1101 MOD. 1.4



TALLEY DEFENSE SYSTEMS Talley

3500 NORTH GREENFIELD ROAD P O BOX 849
MESA, ARIZONA 85201
(602) 898-2200

TABLE

ADVANTAGES AND DISADVANTAGES OF GAS GENERATOR BODY SHAPES

	SMOOTH CURVE	STRAIGHT	45 BEND	CONCENTRIC	CURVED NOZZLE	90 NOZZLE	RIGHT ANGLE	
IMPINGEMENT RESISTANCE	XXX		XXX		XXX	XXX	XXX	ADVANTAGE
		XXX		XXX				DISADVANTAGE
EASE OF MAINTANCE		XXX		XXX				ADVANTAGE
	XXX		XXX		XXX	XXX	XXX	DISADVANTAGE
CONNECTIONS TO SYSTEM		XXX		XXX				ADVANTAGE
	XXX		XXX		XXX	XXX	XXX	DISADVANTAGE
SPACE REQUIREMENT		XXX		XXX				ADVANTAGE
	XXX		XXX		XXX	XXX	XXX	DISADVANTAGE

TABLE 4
GAS GENERATOR SYSTEM

MATERIAL PROPERTIES

MATERIAL	COST 1 SQFT OF 1 INCH THICH	CORROSION RESISTANCE	RELATIVE MATERIAL DENSITY	WELDABILITY BONDABILITY	TENSILE STRENGTH (PSI)	MODULUS OF ELASTICITY (PSI)	SHEAR MODULUS (PSI)
MILD ROLLED STEEL A-36	$35.00	POOR	0.283	POOR	58 x 10^3	29 x 10^6	23 x 10^6
0.3% CARBON STEEL - MILD	$19.00	POOR	0.283	POOR	58 x 10^3	29 x 10^6	23 x 10^6
STAINLESS STEEL TYPE 304	$75.00	EXCELLENT	0.29	EXCELLENT	82 x 10^3	28 x 10^6	23 x 10^6
ALUMINUM 6061 T-6 (HEAT TREATED)	$75.00	GOOD	0.098	EXCELLENT	45 x 10^3	10 x 10^6	3.4 x 10^6
NYLON 6/6	$25.00	EXCELLENT	0.0423	EXCELLENT	12.6 x 10^3	4.2 x 10^6	9.2 x 10^6
UHMW POLYETHYLENE	$7.00	EXCELLENT	0.035	EXCELLENT	4 x 10^3		

TABLE 5
GAS GENERATOR SYSTEM

ADVANTAGES AND DISADVANTAGES OF GAS GENERATOR BODY MATERIALS

	MILD ROLLED STEEL A-36	0.3% CARBON STEEL MILD	STAINLESS STEEL TYPE 305	ALUMINUM 6061 T-6 HEAT TREATED	NYLON 6/6	UHMW POLYETHYLENE	
TENSILE STRENGTH	XXX	XXX	XXX				ADVANTAGE
				XXX	XXX	XXX	DISADVANTAGE
SHEAR STRENGTH	XXX	XXX	XXX				ADVANTAGE
				XXX	XXX	XXX	DISADVANTAGE
WELDABILITY BONDABILITY			XXX	XXX	XXX	XXX	ADVANTAGE
	XXX	XXX					DISADVANTAGE
CORROSION RESISTANCE			XXX	XXX	XXX	XXX	ADVANTAGE
	XXX	XXX					DISADVANTAGE
THERMAL FATIGUE	XXX	XXX	XXX				ADVANTAGE
				XXX	XXX	XXX	DISADVANTAGE

TABLE 6 - SUMMARY OF TESTS	
TEST NUMBER	**DESCRIPTION**
1	Evaluation of varying gas pressure supplied to the actuator piston. Determination of operating and optimal accumulator pressures.
2	Establish the amount of work required to recharge the hydraulic / pneumatic accumulator from 1000 to 3000 PSI.
3	Demonstrate the sequencing of an actuator piston by a binary valve arrangement.
4	Simulation of four actuator pistons operated in sequence via a low pressure signal initiated when the hydraulic / pneumatic accumulator pressure drops below 1000 PSI.
5	System test using shop air regulated at 75 PSI to the intensifier for the purpose of timing the cycle of recharging the hydraulic / pneumatic accumulator.
6	Determine characteristics of the solid propellant.
7	Same as test number 5, except that shop air is replaced by gas produced from the solid propellant.
8	Evaluate the muffler / heat exchanger design.
9	Evaluate the performance of the filter and gas regulator.
10	Final demonstration test.

TABLE 7

TEST 1 - BILL OF MATERIALS

ITEM	QUANTITY	DESCRIPTION
1	10 FEET	1/4" O.D. PLASTIC TUBING
2	5	MALE CONNECTOR - 0.25" O.D. TUBE WITH 3/8" NPT
3	3	UNION TEE - 1/4" O.D. TUBE
4	2	1/2" FEMALE BALL VALVE - WITH 3/8" NPT
5	1	FEMALE REGULATOR VALVE (10 TO 125 PSI) -WITH 3/8' NPT
6	1	MALE CONNECTOR 1/4" O.D. TUBE WITH 10/32" NPT
7	1	1/2" PISTON CYLINDER - STAINLESS STEEL WITH 10/32" NPT - FEMALE
8	1	0-60 PSI PRESSURE GAUGE - GLYCERINE WETTED WITH 3/8" NPT MALE
9	1	0-200 PSI PRESSURE GAUGE - WITH 3/8" NPT MALE
10	2	FEMALE CONNECTOR - 1/4" O.D. TUBE WITH 3/8"NPT
11	1	BIMBA AIR RESIVOR - MODEL # D-11846-A4 28.16 CU-IN., 200 PSI MAX
12	1	MILTON - CHECK VALVE - WITH 3/8" NPT MALE
13	100	PRIMERS FOR SHOT GUN SHELLS (FEDERAL)
14	2	WOOD BLOCK 4" X 4" X 6"

TABLE 8

$$\text{PSI} = \frac{\text{FORCE}}{\text{AREA}}$$

$$\underset{\text{(sq. in.)}}{\text{CYL. AREA}} = \pi r^2$$

$$\underset{\text{(lbs.)}}{\text{FORCE}} = \text{PSI} \times \text{AREA}$$

$$\underset{\text{(ft. per sec.)}}{\text{CYL. SPEED}} = \frac{.3208 \times \text{GPM}}{\text{AREA}}$$

$$\text{HORSEPOWER} = \frac{\text{PSI} \times \text{GPM}}{1714}$$

$$\underset{\text{(Fluid motor)}}{\text{HORSEPOWER}} = \frac{\text{TORQUE (in. lbs.)} \times \text{RPM}}{63025}$$

$$\underset{\text{(in. lbs.)}}{\text{TORQUE}} = \frac{\text{PSI} \times \text{DISP. (cu. in.)}}{2\pi}$$

$$\text{RPM} = \frac{231 \times \text{GPM}}{\text{DISP. (cu. in.)}}$$

$$\underset{\text{(Pump outflow)}}{\text{GPM}} = \frac{\text{RPM} \times \text{DISP. (cu. in.)}}{231}$$

NO ALLOWANCE HAS BEEN MADE FOR EFFICIENCY OF COMPONENTS

TABLE 9
GAS GENERATOR SYSTEM FIRING MECHANISM MATRIX

	MATERIAL COST	OPERATIONAL COST	RELIABILITY	MAINTENANCE	SAFETY	DURABILTY	SIMPLICITY	PERFORMANCE	EASE OF OPERATION	SIZE REQUIREMENT	WEIGHTED TOTAL
WEIGHT FACTOR	0.03	0.02	0.05	0.05	0.20	0.05	0.10	0.10	0.20	0.20	1.00
ROTATING FIRING HEAD	3	5	3	4	5	3	3	5	4	5	✓ 4.29
ROTATING CHAMBER	3	5	3	3	4	3	2	3	4	5	3.74
AUTOMATIC CARTRIDGES	2	4	2	4	3	4	4	4	4	3	3.44
BOLT ACTION	2	4	5	5	3	4	5	2	2	1	2.74

1 2 3 4 5
POOR ⟶ EXCELLENT

TABLE 10

TEST 1 GAS PRESSURE ON PERCUSSION PRIMERS

PRESSURE (PSI)	IGNITION YES	IGNITION NO	COMMENTS
30		X	
45		X	SAME PRIMER
70		X	SAME PRIMER
83		X	SAME PRIMER
80		X	SAME PRIMER
85		X	REMOVED PRIMER AND IGNITED WITH A HAMMER ON CONCRETE (CHECKED PRIMER)
85		X	SHARPENED END OF PISTON AND INCREASED STROKE LENGTH
85		X	SAME PRIMER
70		X	SAME PRIMER
90		X	REMOVED ALL COMPONENTS BETWEEN MANUAL VALVE AND PISTON (REDUCE HEAD LOSS)
80		X	CHANGED TO A .22 CALIBER BLANK
90		X	FILED PISTON HEAD (MORE BLUNT)
90		X	MOVED PISTON CLOSER TO RIM
90		X	CHANGED PRIMER TO SMALL CALIBER
90		X	
90		X	CHANGED TO WINCHESTER 12 GAUGE PRIMER
90		X	SAME PRIMER
90		X	SAME PRIMER
90		X	REMOUNTED PRIMER IN TEST BLOCK
90		X	SAME PRIMER
90		X	SAME PRIMER
90	X		NEW PRIMER - READJUSTED HOLDER
90	X		
80		X	
90	X		SAME PRIMER
90	X		
80		X	
80	X		SAME PRIMER
75	X		
60		X	
60	X		SAME PRIMER
55	X		
50	X		
45	X		

TABLE 10 (continued)

TEST 1 GAS PRESSURE ON PERCUSSION PRIMERS

PRESSURE (PSI)	IGNITION YES	NO	COMMENTS
40		X	
40		X	SAME PRIMER
40		X	SAME PRIMER
35		X	
35	X		SAME PRIMER
35	X		
35		X	
35		X	SAME PRIMER
35		X	SAME PRIMER
35		X	SAME PRIMER - BAD PRIMER - DUD
85		X	SLOW VALVE OPENING - BAD HIT
60	X		CHANGED PRIMERS TO FEDERAL BRAND
40	X		MADE PISTON HEAD BLUNTER
35		X	
34		X	
34	X		SAME PRIMER
35		X	
35		X	SAME PRIMER
35	X		SAME PRIMER
34		X	
33		X	SAME PRIMER
32	X		SAME PRIMER - CENTERED FIRING PIN
31		X	ADDED A METAL PLATE TO THE WOOD 4X4 TO INCREASE IMPACT FORCE
31		X	SAME PRIMER
30		X	SAME PRIMER
29		X	SAME PRIMER
29		X	SAME PRIMER
41		X	SAME PRIMER
60		X	
60		X	SAME PRIMER
60		X	SAME PRIMER
60		X	TESTED PISTON STROKE LENGTH (MAY BE SMALLER DUE TO PLATE)
			MAX=1.4375",RETRACTED=0.875",TEST LENGTH=1.3125
50		X	MADE PRIMER IN PLATE TIGHTER

TABLE 10 (continued)

TEST 1 GAS PRESSURE ON PERCUSSION PRIMERS

PRESSURE (PSI)	IGNITION YES	IGNITION NO	COMMENTS
55		X	SAME PRIMER
60		X	SAME PRIMER
60		X	SAME PRIMER
60		X	SAME PRIMER
60		X	SAME PRIMER
58		X	SAME PRIMER
56		X	SAME PRIMER
55		X	SAME PRIMER
55		X	NEW PRIMER - WINCHESTER
55		X	NEW PRIMER - FEDERAL
58	X		DRILLED HOLE IN BLOCK - FITTED WITH DIAL - TIGHTER
45		X	
45		X	SAME PRIMER
45	X		SAME PRIMER
40	X		MOUNTED BLOCKS TIGHTER
35	X		
30	X		
28	X		
26	X		
24		X	
24		X	SAME PRIMER - PIN NOT CENTERED
28.5	X		
28.5		X	
27.5		X	RELIEF VALVE OPEN
28	X		
35		X	
29		X	
30	X		SAME PRIMER
30		X	
30	X		SAME PRIMER
30		X	
30	X		SAME PRIMER
32.5	X		
31.5	X		

TABLE 10 (continued)

TEST 1 GAS PRESSURE ON PERCUSSION PRIMERS

PRESSURE (PSI)	IGNITION YES	IGNITION NO	COMMENTS
31		X	
31	X		SAME PRIMER
32		X	PIN NOT CENTERED
35	X		SAME PRIMER
35	X		
35	X		
35	X		

CONFIDENCE INTERVAL OF 95 % WITH ALPHA=.025, ERROR=NONE (ALWAYS FIRES)

SIGMA=1 (1 HIT), SAMPLE SIZE = 1.96^2 = 4 FIRINGS WITHOUT A MIS FIRE

THEREFORE FROM ABOVE DATA PISTON PRESSURE > 30 PSI

FACTOR OF SAFETY = 2

RECOMMENDED PISTON PRESSURE = 60 PSI

TABLE 11
GAS GENERATOR SYSTEM FUEL CARTRIDGE MATRIX

	BURN RATE	MATERIAL COST	RELIABILITY	CORROSIVITY	ENERGY DENSITY	SAFETY	ENVIRONMENTAL EFFECTS	MATERIAL AVAILABILITY	REQUIRED VOLUME	SHELF LIFE	WEIGHTED TOTAL
WEIGHT FACTOR	0.15	0.02	0.01	0.10	0.15	0.10	0.12	0.05	0.14	0.16	1.00
RUBBER/AMMONIUM NITRATE	2	4	4	2	3	2	2	2	5	3	2.79
SODIUM AZIDE/ COPPER OXIDE 1104	1	4	5	5	4	3	5	3	3	5	3.65
SODIUM AZIDE/ COPPER OXIDE 1101M	5	4	5	5	4	5	5	3	3	5	4.45
HYDRAZINE	2	3	3	1	5	1	1	2	4	2	2.44
COMPRESSED AIR	5	5	5	5	1	3	5	5	1	5	3.64

1 2 3 4 5
POOR → EXCELLENT

TABLE 12

PROPELLANT PROPERTIES

Description	Rubber/Ammonium Nitrate
Burning rate (r_b) [@ chamber pressure of 6.89 MPa (1000psi)]	.00198 m/s (.078 inches/s)
Flame temperature	1195 C (2183 F)
Density	1.47 gm/cc (.053 lb/cu in)
Heat or Reaction	1420 cal/gm (1162 BTU/lb)
Gas Composition (Moles %)	C_2H_4 4.30 H_2 24.80 N_2 21.98 CO 16.61 H_2O 28.65 FeO .02 CO_3 3.61 HN .02

Data taken from:

Anderson, L.A. and Henry, R. L., "Alternate Power Sources for Wheelchairs", University of Central Florida, College of Engineering, December, 1983.

and

Anderson, L.A., and Henry, R.L., "A study of Alternate Power Sources for Wheelchairs with Implications for Rural Rehabilitation Applications", University of Central Florida, College of Engineering, October, 1984,

TABLE 13

propellant data sheet

TALLEY DEFENSE SYSTEMS | Talley Industries

TAL-1104

Description: Sodium Azide — Copper Oxide

BALLISTIC PROPERTIES:

Burning Rate Equation (80°F) .... $r_b = 1.51(Pc/1000)^{0.16}$

Area Ratio Equation (calc, 80°F) .... $k_n = 110(Pc/1000)^{0.84}$

Temperature Sensitivity (%/°F)

Temperature Range -30° to +160°F .... $\pi_k = 0.19$

THEORETICAL PROPERTIES: ①

Flame Temperature (°F) 1987

Characteristic Exhaust Velocity (C*, ft/sec) 2265

Specific Impulse (1000 psia in std. atmosphere, lbf-sec/lbm) exit 116.5

Molecular Weight, Gas (avg) 27.74

Ratio of Specific Heats (γ) 1.124

Enthalpy (cal/gram) ② .... -106.8

Approximate Gas Composition (Wt. %) Exhaust (1 Atm)

N_2	41.0	$Na_2O(s)$	28.4
Na(g)	2.2	Cu(s)	28.4

Molecular Weight Exhaust Gas 27.74

PHYSICAL PROPERTIES:

Form: Powder or Pressed Grain

Density (lb/in^3, 75°F) .... .0855

Autoignition: > One hour at 700°F

ICC Classification .... Explosive, Class B

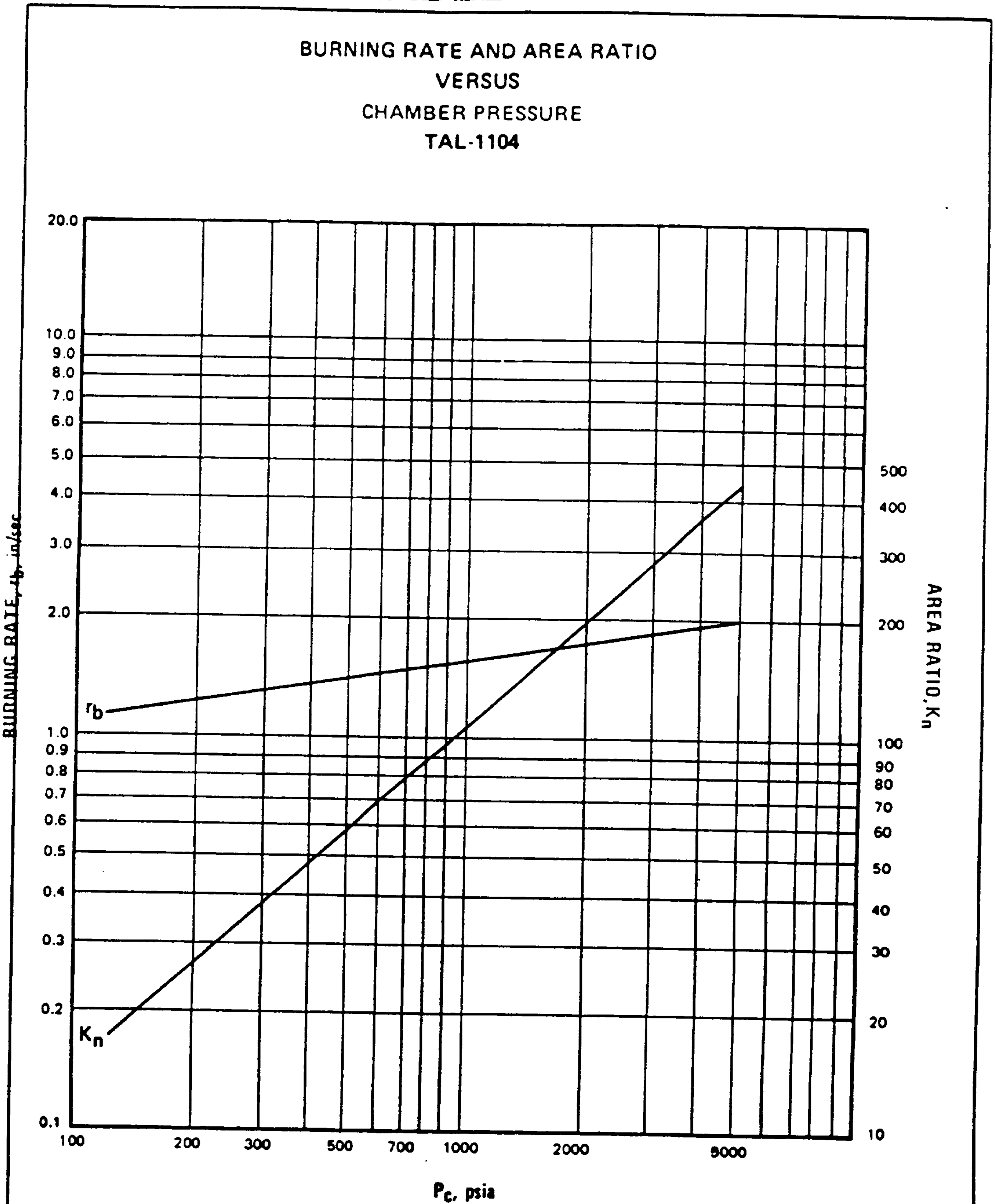
① *Shifting equilibrium calculations, chamber conditions except as noted.*

② *From Navy Performance Evaluation Program, Report Number NWCTP 6037.*

July 1984

MORE TECHNICAL DATA ON REVERSE SIDE

TABLE 14



TALLEY DEFENSE SYSTEMS | Talley Industries

3500 NORTH GREENFIELD ROAD P.O. BOX 849
MESA, ARIZONA 85201
(602) 898-2200
TWX No. 910-953-1681 TELEX No. 667-408

TABLE 15

LIST OF CARTRIDGE SUPPLIERS

AAC ACTION AIR CORPORATION UNIT E, 20957 CURRIER ROAD WALNUT, CA 91789	(714) 595-1770
ACTION MANUFACTURING COMPANY 100 E. ERIE AVENUE PHILADELPHIA, PA 19134 (FRIEDMAN, LEONARD)	(215) 739-6400 FAX: (215) 423-7749
AERO SYSTEM, INC. 5415 N.W. 36TH STREET MIAMI, FL 33166-5899 (AL GOODMAN)	(305) 871-1300 (800) 327-0741
ALLIED INTERNATIONAL CORPORATION 5 DAKOTA DRIVE, SUITE 107 LAKE SUCCESS, NY 11042-1109 (GEORGE SANKY)	(516) 326-2244 FAX: (516) 326-2650
CARTRIDGE ACTIVATED DEVICES 123 CLINTON ROAD FAIRFIELD, NJ 07006 (ED SOOHOO)	(201) 575-1312 (201) 347-2281
COMPRESSED AVIATION GASES 491A WASHINGTON AVENUE CARLSTADT, NJ 07072	(201) 507-8855

TABLE 15 (continued)

EAGLE-PITCHER INDUSTRIES ELECTRONICS DIVISION P.O. BOX 1605 JOPLIN, MO 64802 (JIM HARVEL)	(417) 623-8000, X235
PROPELLEX CORPORATION, ESSEX INDUSTRIES 7700 GRAVOIS AVENUE (W) ST. LOUIS, MO 63123-4728 (RON JONES)	(618) 656-3400 (314) 632-4500
EXPLOSIVE TECHNOLOGY, INC. P.O. BOX KK FAIRFIELD, CA 94533-0659	(707) 422-1880
HILL AVIATION LOGISTICS 19734 DEABORN STREET CHATSWORTH, CA 91311	(818) 885-0300
HI-SHEAR TECHNOLOGY CORPORATION 24225 GARNIER TORRANCE, CA 90505	(213) 326-8110
HRD AERO SYSTEMS, INC. 27811 HOPKINS AVENUE, SUITE 4 VALENCIA, CA 91355	(805) 295-0670
HTL ENERGY SYSTEMS DIVISION 7073 WEST WILLIS DRIVE CHANDLER, AZ 85224	(602) 961-1100
ICI AMERICAS, INC., AEROSPACE DIVISION P.O. BOX 819 VALLEY FORGE, PA 19482	(215) 666-8600

TABLE 15 (continued)

IRECO, INC. PORT EWEN PLANT PORT EWEN, NY 12466 (BOB RAPANT)	(914) 338-2144 (914) 334-3295
KILGORE CORPORATION BRADROAD ROAD TOONE, TN 38381	(901) 658-5321
LORAL HYCOR, INC. 10 GILL STREET WOBURN, MA 01801	(617) 935-5950
LUCAS AEROSPACE INC. 11150 SUNRISE VALLEY DRIVE RESTON, VA 22091-4399 (MARTIN BUTTERY, MARK WELCH)	(201) 567-6400
MEREX, INC. 5137 N. CLARETON STREET, SUITE 220 AGOURA, CA 91301	(818) 889-2358
OEA, INC. P.O. BOX 100488 DENVER, CO 80250 (TOM GRAVES)	(303) 693-1248
ORDTRONEX CORPORATION 112 W. JULIE DRIVE TEMPE, AZ 85283	(602) 839-5811
PACIFIC AERODYNE 9255 GLENOAKE BOULEVARD SUN VALLEY, CA 91352	(818) 767-1611

TABLE 15 (continued)

ROCKET RESEARCH COMPANY P.O. BOX 97009 REDMOND, WA 98073-9709 (LYLE GALBRAITH)	(206) 885-5000
SIEBELAIR CORPORATION 5563 W. WASHINGTON BOULEVARD CA 90016	(213) 939-2183
SPECIAL DEVICES, INC. 16830 W. PLACENTA CANYON ROAD NEWHALL, CA 91321	(805) 259-0753
STRESAU LABORATORY, INC. 1400 S. RIVER STREET SPOONER, WI 54801 (JIM GRABER)	(715) 635-2777 (715) 635-7979
THIOKOL CORPORATION, ORDNANCE OPERATIONS 401 MARKET STREET, SUITE 1120 SHREVEPORT, LA 71101	(318) 222-7675
UNIDYNAMICS PHOENIX, INC. 1000 N. LITCHFIELD ROAD GOODYEAR, AZ 85338	(602) 932-8100
U.S. ROCKETS 195 SAN LORENZO POMONA, CA 91766	(714) 622-3111
WHITTAKER ORDNANCE P.O. BOX 148 2751 SAN JUAN ROAD HOLLISTER, CA 95024-0148	(408) 637-5851

TABLE 15 (continued)

WICKMAN SPACECRAFT & PROPULSION COMPANY
P.O. BOX 7179
CITRUS HEIGHTS, CA 95621-7179

TABLE 15 (continued)

LIST OF SODIUM AZIDE CHEMICAL SUPPLIERS

AMERICAN INTERNATIONAL CHEMICAL, INC. 27 STRATHMORE ROAD NATICK, MA 01760	(508) 655-5805 (800) 238-0001
AMERICAN RESEARCH PRODUCTS CO. (AMRESCO) P.O. BOX 39098 30175 SALON INDUSTRIAL PARKWAY SALON, OH 44139	(216) 349-1199 (800) 829-2802 FAX: (216) 439-1182
CHARKIT CHEMICAL CORPORATION 330 POST ROAD P.O. BOX 1725 DARIEN, CT 06820	(203) 665-3400 FAX: (203) 655-8643
FAIRMONT CHEMICAL CO., INC. 117 BLANCHARD STREET NEWARK, NJ 07105	(201) 344-5790 (800) 872-9999 FAX: (201) 169-0529 8
MAYPRO INDUSTRIES, INC. 550 MAMARONECK AVENUE HARRISON, NY 10528	(914) 381-3808 FAX: (914) 381-3815
PSI CHEMICALS DIVISION PLUESS - STAUFER INTERNATIONAL, INC. 655 WASHINGTON BOULEVARD, SUITE 900 STAMFORD, CT 06901	(203) 328-3200 FAX: (203) 976-8977
S.S.T. CORPORATION 635 BRIGHTON ROAD CLIFTON, NJ 07015-1649	(201) 473-4300 FAX: (201) 473-4326

TABLE 15 (continued)

SCHWEIZERHALL, INC.
10 CORPORATE PLACE
SOUTH PISCATAWAY, NJ 08854

(908) 981-8200
FAX: (908) 981-8282

TABLE 16

RESULTS OF CARTRIDGE TESTING

TEST NO.	STARTING TEMP. (°F)	HIGH TEMP	PRESSURE (PSI)
1	83	717	---
2	83	682	45
3	88	867	50
4	84	412	115
5	93	712	110

TABLE 17
GAS GENERATOR BODY SHAPE MATRIX

SHAPE	PRESSURE DROP	COST	FITTINGS	SPACE	RELIABILITY	MAINTENANCE	ADAPTABILITY	IMPINGMENT RESISTANCE	COMMERCIAL AVAILABILITY	WEIGHTED TOTAL
WEIGHT FACTOR	0.25	0.02	0.15	0.15	0.03	0.05	0.15	0.15	0.05	1.00
SMOOTH CURVE	3	4	2	3	4	4	3	4	4	3.15
RIGHT ANGLE	2	4	3	3	4	4	3	3	4	2.90
STRAIGHT	5	5	3	4	5	5	4	5	5	4.40
45 BEND	2	3	2	3	4	4	2	3	3	2.53
CONCENTRIC	4	2	5	5	5	5	5	5	5	✓ 4.69
CURVED NOZZLE	2	1	1	2	3	3	1	3	1	1.86
90 NOZZLE	1	1	1	1	3	3	1	2	1	1.31

1 2 3 4 5
POOR → EXCELLENT

TABLE 18
GAS GENERATOR BODY MATERIAL MATRIX

MATERIAL	WELD/BOND	COST	FITTINGS	MANUFACTURING	RELIABILITY	AVAILABILITY	CORROSION RESISTANCE	DURABILITY (STRENGTH)	WEIGHT	WEIGHTED TOTAL
WEIGHT FACTOR	0.25	0.02	0.15	0.10	0.01	0.02	0.15	0.20	0.10	1.00
MILD ROLLED STEEL A-36	4	2	5	3	5	5	2	4	2	3.54
0.3% CARBON STEEL-MILD	4	3	5	3	5	4	2	4	1	3.44
STAINLESS STEEL TYPE 304	5	1	5	3	5	4	5	5	3	✓ 4.50
ALUMINUM 6061 T-6 (HEAT TREATED)	4	1	4	5	4	3	4	3	4	3.82
NYLON 6/6	3	4	3	2	3	2	5	2	5	3.20
UHMW POLYETHYLENE	3	5	2	4	2	3	5	1	6	3.18

1 2 3 4 5
POOR ⟶ EXCELLENT

TABLE 19
GAS GENERATOR SYSTEM FILTER MATRIX

TYPE OF FILTER	COST	FILTERING ABILITY	RELIABILITY	PRESSURE DROP	STEADY FLOW OUTPUT	FLOW RESISTANCE	COMMERCIAL AVAILABILITY	WEIGHTED TOTAL
WEIGHT FACTOR	0.05	0.20	0.30	0.05	0.05	0.20	0.15	1.00
FIBERGLASS SCREEN	3	4	2	3	3	3	4	3.05
HASTOLY/INCONEL SCREEN	3	4	5	3	3	3	4	3.95
PORUS METAL	1	5	5	1	3	1	3	3.40
CLOTH	5	3	1	3	3	3	5	2.80

1 2 3 4 5
POOR → EXCELLENT

TABLE 20

GAS GENERATOR SYSTEM PRESSURE REGULATOR MATRIX

	COST	SPACE REQUIREMENT	MAINTENANCE	PRESSURE DROP	STEADY FLOW OUTPUT	ADAPTABILITY TO SYSTEM	COMMERCIAL AVAILABILITY	WEIGHTED TOTAL
WEIGHT FACTOR	0.05	0.10	0.15	0.15	0.30	0.15	0.10	1.00
SHARP EDGE ORIFICE	5	5	3	5	2	5	5	3.80
CAVITATING VENTURI	4	2	5	2	4	3	1	3.20
NOZZLE	3	3	4	3	3	3	3	3.15
FLOW RATE CONTROLLER	2	2	2	5	5	4	4	✓ 3.85
REDUCING VALVE	1	2	3	4	4	4	4	3.50

1 2 3 4 5

POOR ——→ EXCELLENT

TABLE 21

FLOW (GPM)	PRESSURE (PSI)	CALCULATED PRESSURE (PSI) LINEAR	CALCULATED PRESSURE (PSI) 5th ORDER
0.1425	3350	3292	3378
0.1900	2900	2888	2987
0.2375	2440	2484	2462
0.2850	2000	2080	1980
0.3325	1625	1676	1634
0.3800	1375	1272	1373

Regression Output:		
Constant		4503.6666667
Std Err of Y Est		79.141223982
R Squared		0.9913049514
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	-8505.2631579	
Std Err of Coef.	398.28149508	

TABLE 21 (continued)

****************** LEAST SQUARES CURVE FITTING PROGRAM ******************

FOR A SET OF PAIRED DATA, THIS PROGRAM WILL CALCULATE LEAST SQUARE CURVE FITS OF NINE MATH FUNCTIONS, AND INDICATE THE RESPECTIVE CORRELATION COEFFICIENTS AND SUM-OF-SQUARES ERRORS

THE PROGRAM WILL EVALUATE THE FOLLOWING 'CURVE FITS' :

1.) LINEAR
2.) EXPONENTIAL (LOGARITHMIC)
3.) POWER
4.) PARABOLIC
5.) POLYNOMIAL --- 3rd DEGREE
6.) POLYNOMIAL --- 4th DEGREE
7.) POLYNOMIAL --- 5th DEGREE
8.) POLYNOMIAL --- 6th DEGREE
9.) POLYNOMIAL --- 7th DEGREE

BY
ROY C. CHETTY
(c) 1986

DESCRIPTION OF THE CURVE: INTENSIFIER OUTPUT VS. PRESSURE @ 10 SCFM

INPUT PARAMETERS

N	X-VALUE	Y-VALUE
1	.1425	3375
2	.19	3000
3	.2375	2440
4	.285	2000
5	.3325	1625
6	.38	1375

TABLE 21 (continued)

```
*    ********************  RESULTS  ****************************************

THE LINEAR CURVE IS OF THE FORM:
             Y= 4591.285 -8760.898 X

CORRELATION COEFFICIENT:  -.9941329          SUM OF SQUARE ERROR:  35877.16
=========================================================================
THE LOGARITHMIC CURVE IS OF THE FORM:
             Y=-671.7253 -4908.844 Log X

CORRELATION COEFFICIENT:  -.9944854          SUM OF SQUARE ERROR:  9.523512E+07
=========================================================================
THE POWER CURVE FIT IS OF THE FORM:
             Y= 590.5606 X^ (-.9394934 )

CORRELATION COEFFICIENT:  -.9812509          SUM OF SOUARE ERROR:  172480.1
=========================================================================
THE PARABOLIC CURVE FIT IS OF THE FORM:
             Y= 5257.615  -14406.31 X+ 10804.61 X^2

CORRELATION COEFFICIENT:   .9977643          SUM OF SQUARE ERROR:   13695.89
=================================================================================
THE 3rd DEGREE POLYNOMIAL IS OF THE FORM:
             Y= 3477.137 + 8769.43 X -83128.27 X^2+ 119844.5 X^3

CORRELATION COEFFICIENT:   .9995043          SUM OF SQUARE ERROR:   3039.1
=================================================================================
TH 4th DEGREE POLYNOMIAL IS OF THE FORM:
             Y=-2700.953 + 115932.7 X -748118.3 X^2+ 1877420 X^3 -1677323 X^4

CORRELATION COEFFICIENT:   .9996926          SUM OF SQUARE ERROR:   1884.774
=================================================================================
THE 5th DEGREE POLYNOMIAL IS OF THE FORM:
             Y= 2001.297 + 26551.98 X -107095.4 X^2 -292942.4 X^3
                + 1789021 X^4 -2080176 X^5

CORRELATION COEFFICIENT:   .9998125          SUM OF SQUARE ERROR:  1149.451
=================================================================================
ERROR IN MATRIX ROUTINES
THE 6th DEGREE POLYNOMIAL IS OF THE FORM:
             Y= 2001.297 + 26551.98 X -107095.4 X^2 -292942.4 X^3
                + 1789021 X^4 -2080176 X^5+ 0 X^6

CORRELATION COEFFICIENT:   .9998125          SUM OF SQUARE ERROR:   1149.451
=================================================================================
ERROR IN MATRIX ROUTINES
THE 7th DEGREE POLYNOMIAL IS OF THE FORM:
             Y= 2001.297 + 26551.98 X -107095.4 X^2 -292942.4 X^3
                + 1789021 X^4 -2080176 X^5+ 0 X^6+ 0 X^7

CORRELATION COEFFICIENT:   .9998125          SUM OF SQUARE ERROR:   1149.451
=========================================================================
```

TABLE 22

CYLINDER SPEED

Pump Delivery (Cu. In. per Min.) = Cylinder Area (Square Inches) × Piston Velocity (Inches per Minute)

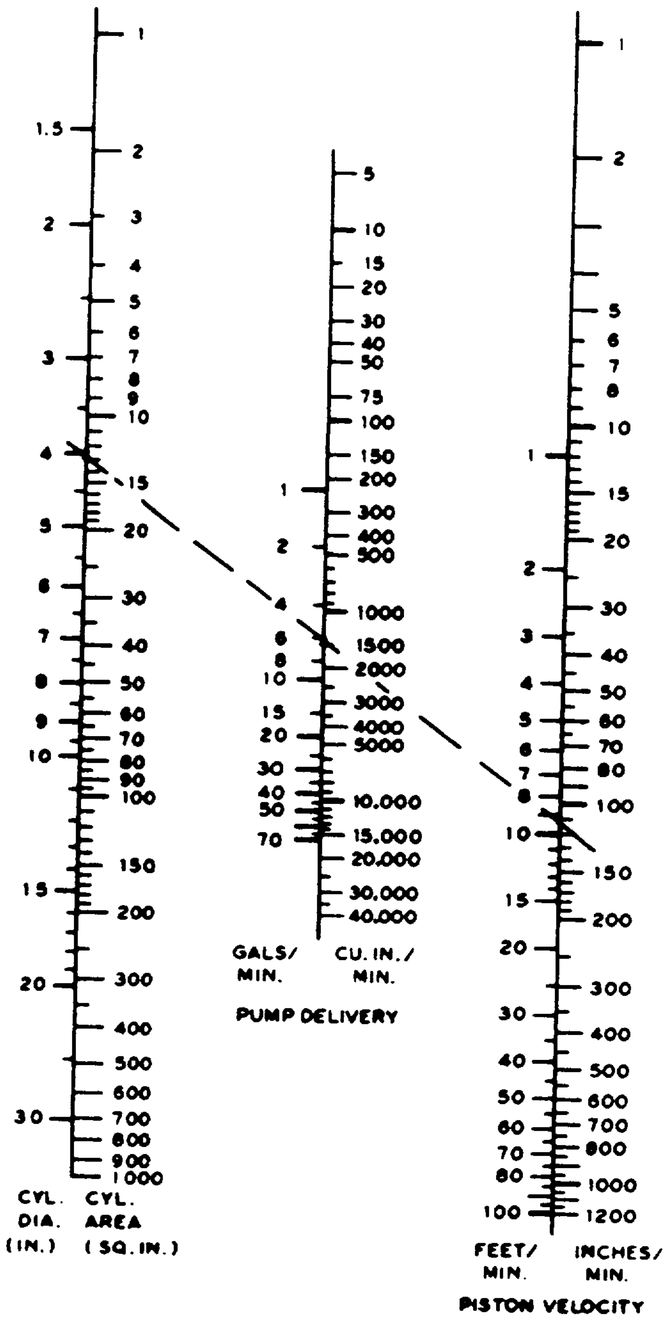


TABLE 23

Gas Generator Body Stress Analysis With Varying Wall Thickness and Pressure.
Using Thin and Thick Walled Vessel Equations
Equation Changes When Wall Thickness Approaches 1/20 of The Diameter.

4" Diameter Outer	Internal Diameter 3 3/4"	Wall Thickness 1/8"	Stress Average Equation =p*d(i)/(2*t)
			Stress Max Equation P(d(i)+t)/(2*t)
			Stress Longitudinal = P*d(i)/(4*t)
Pressure in PSI	Stress Average	Stress Max	Stress Longitudinal
100	1500	1550	750
200	3000	3100	1500
300	4500	4650	2250
400	6000	6200	3000
500	7500	7750	3750
600	9000	9300	4500
700	10500	10850	5250
800	12000	12400	6000
900	13500	13950	6750
1000	15000	15500	7500
1100	16500	17050	8250
1200	18000	18600	9000
1300	19500	20150	9750
1400	21000	21700	10500
1500	22500	23250	11250
1600	24000	24800	12000
1700	25500	26350	12750
1800	27000	27900	13500
1900	28500	29450	14250
2000	30000	31000	15000
2100	31500	32550	15750
2200	33000	34100	16500
2300	34500	35650	17250
2400	36000	37200	18000
2500	37500	38750	18750
2600	39000	40300	19500
2700	40500	41850	20250
2800	42000	43400	21000
2900	43500	44950	21750
3000	45000	46500	22500

TABLE 23 (continued)

Stress Max 1/10"	Stress Max 0.15"	Stress Max 0.175"	Stress Max 0.20"	Stress Max 0.225"	Stress Max 0.25"
1950	1283.3333333333	1092.8571428571	950	838.88888888889	750
3900	2566.6666666667	2185.7142857143	1900	1677.7777777778	1500
5850	3850	3278.5714285714	2850	2516.6666666667	2250
7800	5133.3333333333	4371.4285714286	3800	3355.5555555556	3000
9750	6416.6666666667	5464.2857142857	4750	4194.4444444444	3750
11700	7700	6557.1428571429	5700	5033.3333333333	4500
13650	8983.3333333333	7650	6650	5872.2222222222	5250
15600	10266.666666667	8742.8571428571	7600	6711.1111111111	6000
17550	11550	9835.7142857143	8550	7550	6750
19500	12833.333333333	10928.571428571	9500	8388.8888888889	7500
21450	14116.666666667	12021.428571429	10450	9227.7777777778	8250
23400	15400	13114.285714286	11400	10066.666666667	9000
25350	16683.333333333	14207.142857143	12350	10905.555555556	9750
27300	17966.666666667	15300	13300	11744.444444444	10500
29250	19250	16392.857142857	14250	12583.333333333	11250
31200	20533.333333333	17485.714285714	15200	13422.222222222	12000
33150	21816.666666667	18578.571428571	16150	14261.111111111	12750
35100	23100	19671.428571429	17100	15100	13500
37050	24383.333333333	20764.285714286	18050	15938.888888889	14250
39000	25666.666666667	21857.142857143	19000	16777.777777778	15000
40950	26950	22950	19950	17616.666666667	15750
42900	28233.333333333	24042.857142857	20900	18455.555555556	16500
44850	29516.666666667	25135.714285714	21850	19294.444444444	17250
46800	30800	26228.571428571	22800	20133.333333333	18000
48750	32083.333333333	27321.428571429	23750	20972.222222222	18750
50700	33366.666666667	28414.285714286	24700	21811.111111111	19500
52650	34650	29507.142857143	25650	22650	20250
54600	35933.333333333	30600	26600	23488.888888889	21000
56550	37216.666666667	31692.857142857	27550	24327.777777778	21750
58500	38500	32785.714285714	28500	25166.666666667	22500

TABLE 23 (continued)

	Same As Above Except	
	1/4" Wall Thickness	
Stress Average	Stress Max	Stress Longitudinal
700	750	350
1400	1500	700
2100	2250	1050
2800	3000	1400
3500	3750	1750
4200	4500	2100
4900	5250	2450
5600	6000	2800
6300	6750	3150
7000	7500	3500
7700	8250	3850
8400	9000	4200
9100	9750	4550
9800	10500	4900
10500	11250	5250
11200	12000	5600
11900	12750	5950
12600	13500	6300
13300	14250	6650
14000	15000	7000
14700	15750	7350
15400	16500	7700
16100	17250	8050
16800	18000	8400
17500	18750	8750
18200	19500	9100
18900	20250	9450
19600	21000	9800
20300	21750	10150
21000	22500	10500

TABLE 23 (continued)

LID MOUNTING BOLTS STRESS ANALYSIS

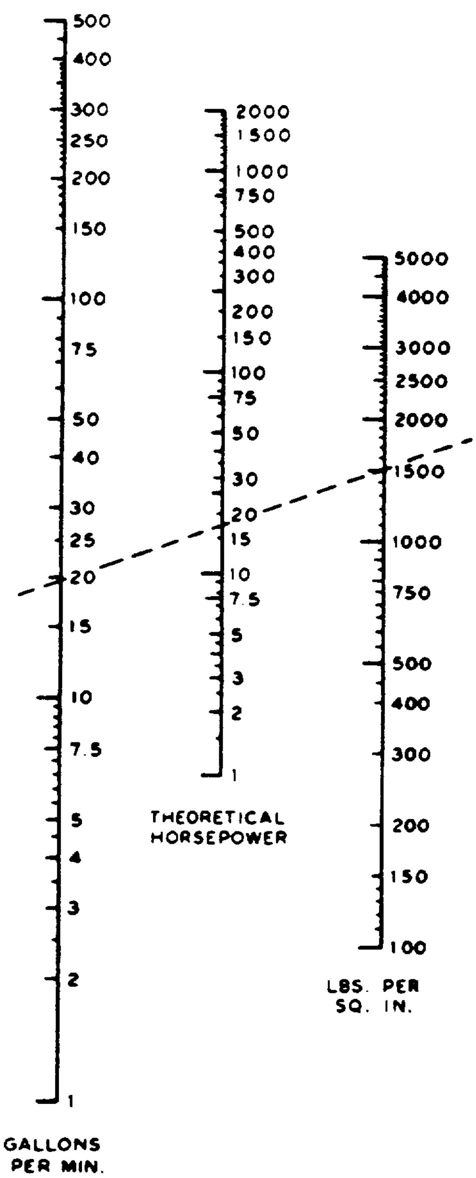
DIAMETER OF LID	AREA OF LID	PRESSURE #1	ON LID IN PSI	USING P#2	USING P #3
IN INCHES	IN INCHES ^ 2	IN PSI		IN PSI	IN PSI
3	7.067925	1000	7067.925	54205.25586548	383118.68306301
3.125	7.669189453125		7669.189453125	58816.46686792	415710.37658747
3.25	8.2949953125	PRESSURE #2	8294.9953125	63615.89056435	449632.34331701
3.375	8.945342578125	IN PSI	8945.342578125	68603.52695475	484884.58325163
3.5	9.62023125	2000	9620.23125	73779.37603912	521467.09639132
3.625	10.31966132813		10319.66132813	79143.43781748	559379.8827361
3.75	11.0436328125	PRESSURE #3	11043.6328125	84695.71228981	598622.94228596
3.875	11.79214570313	IN PSI	11792.14570313	90436.19945612	639196.27504089
4	12.5652	3000	12565.2	96364.89931641	681099.88100091
4.125	13.36279570313		13362.79570313	102481.8118707	724333.76016801
4.25	14.1849328125		14184.9328125	108786.9371189	768897.91253618
4.375	15.03161132813		15031.61132813	115280.2750811	814792.33811144
4.5	15.90283125		15902.83125	121961.8256973	862017.03689178
4.625	16.79859257813		16798.59257813	128831.5890275	910572.00887719
4.75	17.7188953125		17718.8953125	135889.5650517	960457.25406769
4.875	18.66373945313		18663.73945313	143135.7537698	1011672.7724633
5	19.633125		19633.125	150570.1551819	1064218.5640639
5.125	20.62705195313		20627.05195313	158192.769288	1118094.6288697
5.25	21.6455203125		21645.5203125	166003.596088	1173300.9868805
5.375	22.68853007813		22688.53007813	174002.6355821	1229837.5780964
5.5	23.75608125		23756.08125	182189.8877701	1287704.4625173
5.625	24.84817382813		24848.17382813	190565.3528521	1346901.6201434
5.75	25.9648078125		25964.8078125	199129.030226	1407429.0509745
5.875	27.10598320313		27105.98320313	207880.920498	1469288.7550108
6	28.2717		28271.7	216821.0234619	1532474.732252
6.125	29.46195820313		29461.95820313	225949.3391198	1596992.9828984
6.25	30.6767578125		30676.7578125	235265.8674717	1662841.5063499
6.375	31.91609882813		31916.09882813	244770.6085176	1730020.3032064
6.5	33.17998125				

TABLE 24

PUMP and MOTOR HORSEPOWER

HP = PSI X GPM X 0.000583

PUMP DRIVE = THL HP ÷ EFFICIENCY
MOTOR OUTPUT = THL HP X EFFICIENCY



APPENDIX C

WORK BREAKDOWN STRUCTURE REPORT

WORK BREAKDOWN STRUCTURE REPORT

WHEELCHAIR - GAS GENERATOR SYSTEM

UNIVERSITY OF CENTRAL FLORIDA
DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

JANUARY, 1992

Dr. Loren A. Anderson
EML 4502, Engineering Design II

<u>GAS GENERATOR SYSTEM DESIGN TEAM</u> (G^2SDT)

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WHEELCHAIR - GAS GENERATOR SYSTEM

INTRODUCTION

The National Aeronautics and Space Administration (NASA) at Kennedy Space Center (KSC) shares a common interest with the public. This interest is in improving the quality of life through the development of sound engineering techniques and methodology. In recent years, the NASA has specifically shown interest in the evolution of alternative power sources for wheelchairs.

The University of Central Florida (UCF) and KSC have taken an active role in a joint effort to investigate the possibilities of alternative power sources and to develop the optimum alternative that will provide an advanced 21st Century Wheelchair design. A design team comprised of students in the Spring-1992 Senior Mechanical and Aerospace Engineering design class at the University of Central Florida, are exploring the aspects of this design. This development is through the design of a gas generator system used in powering a hydraulic motor.

The purpose of this report is to establish and present the rudimentary outline and schedule for completing the component design, testing and presentation of a prototype gas generator system. This document will be revised to incorporate the progress of the design team's efforts in completing the gas generator system. Figure 1 shows a schematic of the major components of the gas generator system.

DISCUSSION

The construction of this system is divided into eight major tasks as follows:

1. Review requirements
2. Calculations
3. Drawings
4. Reports
5. Fabrication
6. Procurement
7. Testing
8. Finalization

A construction schedule with required completion dates and team personal responsibility is shown in Table 1 of this report. Table 2 provides a dictionary of the items in Table 1. A task leader is assigned to each major task and is responsible for monitoring the progress and completion of each task. The details of each sub-task are discussed in this report.

A. Review Requirements

This task involves a review of the gas generator system, explanation of the major components, and discussion of the work breakdown structure and construction schedules. In addition, the previous design groups' final report and all drawings and calculations are reviewed.

B. Calculations

Calculations are needed to assist in the optimization of the final design, procurement of components, provide a basis for comparison of test results and are necessary for sizing system components.

The gas volume and burning rate per weight of fuel is necessary to size the fuel cartridges. The fuel used in this application is a slow burning derivative of the chemical compound, Sodium Azide - Copper Oxide that expels nitrogen gas. The gas pressure produced by this fuel will be determined by the amount of fuel and the total volume of the system.

Calculations of the total gas generator system volume utilizing different flow devices are important in determining the need for and size of an accumulator. Inlet and exit pressures of various orifices and venturies are calculated to provide evidence of the optimal choice in flow regulation and assistance in determining the system pressure requirements.

The striking force provided by the firing head enabling ignition of the fuel cartridges is determined by the spring mechanism of the firing head. The determination of the spring constant necessary for ensuring ignition is essential in obtaining the correct size spring for the firing head.

Calculations of heat transfer are performed on the muffler/heat exchanger to determine the necessity of utilizing the hydraulic fluid to remove exhaust heat. This hydraulic fluid is pumped into the muffler/heat exchanger in a counter flow direction.

Calculations are performed to determine system performance for nitrogen at high temperatures. Testing of the gas generator system and each of its components determines the system's performance at ambient temperatures.

C. Drawings

Drawings of each component are developed for procurement and fabrication purposes.

D. Reports

Preparation and presentations of reports are included in the work breakdown structure to assist in the evaluation and determination of man power for scheduling purposes.

E. Fabrication

With the exception of fabricating thermocouples for use in testing and assembling the gas generator system, all fabrication of the system's components will be performed by NASA or procured from a component vendor.

F. Procurement

All major components are acquired from the component supplier. Instrumentation and tools will be supplied by UCF and/or members of the design team.

G. Testing

Testing of two different intensifiers is performed. An intensifier with a self contained reservoir and an intensifier with an external sump are tested to determine performance. The results of these tests are utilized to calculate requirements of output from the gas generator system and quantity of sodium azide -copper oxide solid fuel.

Testing of a prototype muffler/heat exchanger is performed to determine the necessity of utilizing the hydraulic fluid to remove heat from exhaust gas.

An electric low pressure sensor and servo mechanism are utilized to prove in principle the rotation and ignition sequence of the firing mechanism.

Sodium azide - copper oxide solid fuel is tested for temperature, burning rate, volume and pressure of gas produced.

The assembled gas generator system is tested to finalize the presentation of a working prototype.

F. Fianalization

Finalization of the project involves presentation of a working prototype, test results, drawings and calculation to UCF and NASA. In addition a video tape of the testing and prototype will be produced.

Figure 2 depicts the work breakdown schedule in block form. The gantt chart shown in figure 3 is utilized in determining the critical path of scheduled work. Project milestones are shown in figure 4 and depict a summary of work to be performed and display progress.

SUMMARY

The preceding sections have discussed the basic construction schedule and work breakdown structure associated with testing and fabricating the gas generator system. The challenge of designing this system provides UCF engineering students with a bridge between the classroom and the professional engineering environment.

There has been a great deal of significant development and investment in recent years through the efforts of KSC and UCF on this project. Involvement of UCF provides for the professional development necessary to structure this idea into reality and develop a working prototype.

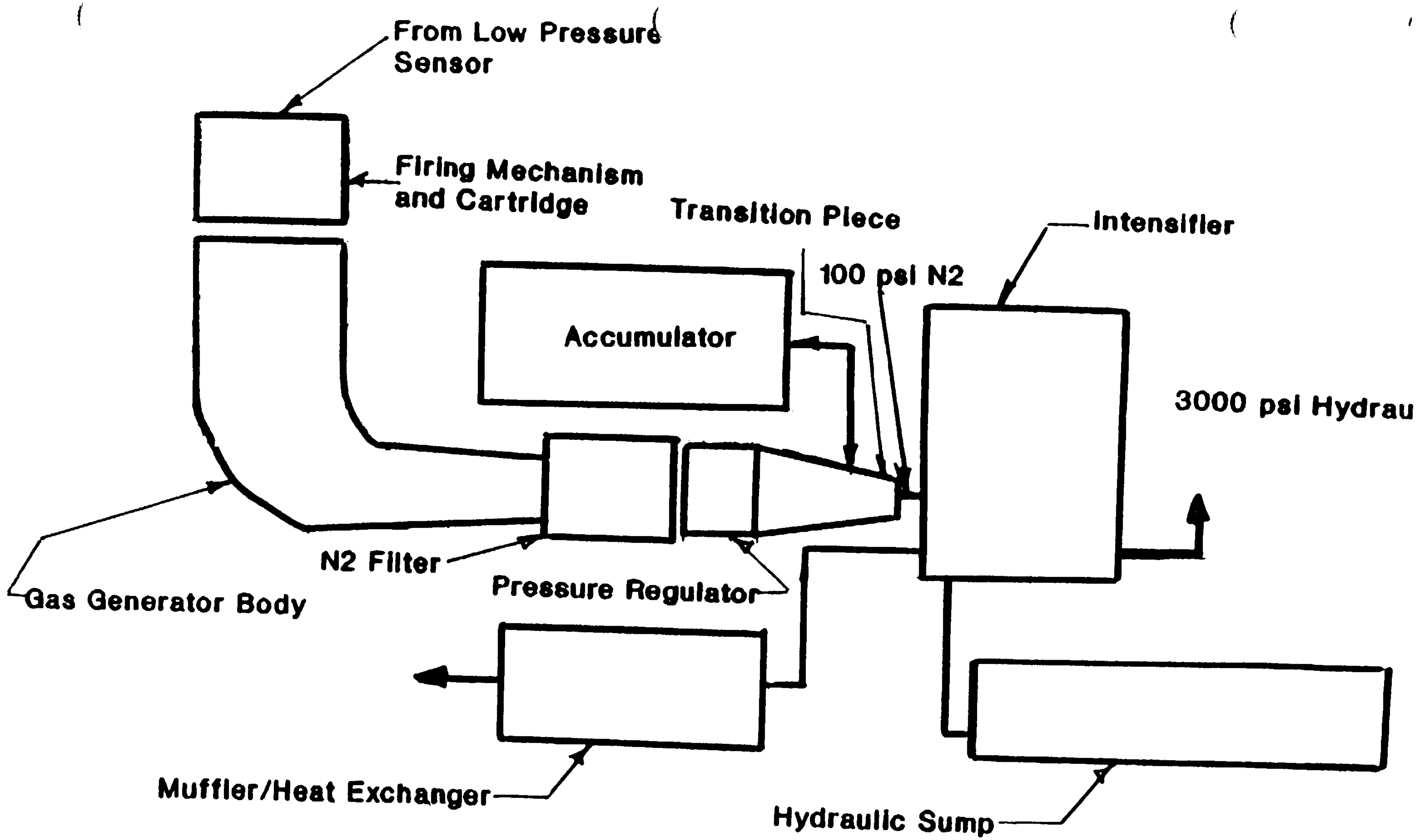

FIGURE 1
GAS GENERATOR

WHEELCHAIR - GAS GENERATOR SYSTEM
CONSTRUCTION SCHEDULE

	TASK	REQUIRED DATE	RESPONSIBILITY
A.	Review Requirements	1/15/91	W.E.
A.1	Review Final Report	1/15/91	ALL
A.2	Review Drawings	1/15/91	ALL
A.3	Review Calculations	1/15/91	ALL
B.	Calculations		L.M.
B.1	Gas volume and burning rate per weight of fuel	2/15/91	R.T. - L.M.
B.2	Flow regulation device size (inlet/exit pressures)	3/14/91	
B.2.1	Orifice	3/14/91	D.G. - W.E.
B.2.2	Venturi	3/14/91	D.G. - W.E.
B.3	System Volume		
B.3.1	Orifice	3/14/91	D.L. - W.E.
B.3.2	Venturi	3/14/91	D.L. - W.E.
B.3.3	Flow regulator	3/14/91	D.L. - W.E.
B.4	Need for an accumulator	3/14/91	D.L. - W.E.
B.5	Gas (N_2) pressure produced per weight of fuel	3/28/91	R.T. - L.M.
B.6	Firing mechanism spring constant	???????	O.F.
B.7	Muffler/Heat exchanger		
B.7.1	Counter flow heat exchange	3/21/91	L.M. - W.E.
B.8	Corrections for "hot nitrogen" vs. tested "cold air"	3/28/91	D.G. - W.E.
C.	Drawings		D.G.
C.1	Fuel cartridges	3/28/91	R.T. - D.G.
C.2	Gas generator body	2/15/91	D.G.
C.3	Filter	2/15/91	W.E. - D.G.
C.4	Flow regulation	2/22/91	D.G.
C.4.1	Venturi	2/22/91	D.G.
C.4.2	Orifice	2/22/91	D.G.
C.5	Transition pieces	2/29/91	D.L. - D.G.
C.6	Muffler/Heat exchanger	3/21/91	L.M. - D.G.

TABLE 1

WHEELCHAIR - GAS GENERATOR SYSTEM
CONSTRUCTION SCHEDULE

D.	Reports		W.E.
D.1	UCF		
D.1.1	Work breakdown structures	1/15/91	D.L. - W.E.
D.1.2	Construction and test plan	3/18/91	D.G. - W.E.
D.1.3	Tests	4/20/91	W.E. - W.E.
D.1.4	Technical discussion - Fuel	2/10/91	R.T. - W.E.
D.1.5	Technical discussion - Hydraulics or case study	2/24/91	L.M. - W.E.
D.2	NASA		
D.2.1	Engineering	4/25/91	W.E. - O.F.
D.2.1.1	Drawings	4/25/91	W.E. - O.F.
D.2.1.2	Calculations	4/25/91	W.E. - O.F.
D.2.1.3	Video tape	4/25/91	W.E. - O.F.
D.2.2	Tests	4/25/91	W.E. - O.F.
E.	Fabrication		D.L.
E.1	NASA		
E.1.1	Firing mechanism	???????	O.F.
E.1.2	Flow regulation devices	???????	O.F.
E.1.3	Venturi	???????	O.F.
E.1.4	Orifice	???????	O.F.
E.2	Gas generator system	2/29/91	D.G.
E.3	Thermocouples (type K)	2/01/91	D.G.
F.	Procurement		R.T.
F.1	Intensifier		
F.1.1	HEYPAC (with sump)	2/08/91	W.E.
F.1.2	Without sump	2/08/91	W.E.
F.2	Instrumentation		
F.2.1	Hot gas flow meters	2/01/91	D.G.
F.2.2	Thermocouples	2/01/91	D.G.
F.2.3	Flow meters	2/01/91	D.G.
F.2.4	Pressure gauges	2/01/91	D.G.
F.2.4.1	Static	2/01/91	D.G.
F.2.4.2	Pressure differential	2/01/91	D.G.
F.2.5	12 volt supply system	2/01/91	D.G.
F.2.5.1	Transformer	2/01/91	D.G.
F.2.5.2	Battery	2/01/91	D.G.

WHEELCHAIR - GAS GENERATOR SYSTEM
CONSTRUCTION SCHEDULE

F.3	Hydraulic sump (reservoir)	2/15/91	R.T.
F.4	Hydraulic piping/tubing	2/15/91	L.M.
F.5	Electric low pressure sensor	3/07/91	L.M.
F.6	Low pressure servo	3/07/91	L.M.
F.7	Stop watch	2/01/91	L.M.
F.8	Tools		
F.8.1	Standard and metric sockets	2/01/91	L.M.
F.8.2	Open end wrenches	2/01/91	L.M.
F.8.3	Adjustable wrenches	2/01/91	L.M.
F.8.4	Pliers		
F.8.4.1	Needle nose	2/01/91	L.M.
F.8.4.2	Flat head	2/01/91	L.M.
F.8.5	Channel locks	2/01/91	L.M.
F.8.6	Wire cutter	2/01/91	L.M.
F.8.7	Screwdrivers		
F.8.7.1	Phillips head	2/01/91	L.M.
F.8.7.2	Flat Head	2/01/91	L.M.
F.8.8	Hammer	2/01/91	L.M.
F.9	Flow Rate Controller (W.A. Kates Co.)	2/22/91	W.E.
F.10	Stainless steel tubing (Type 304)	2/22/91	D.L.
F.11	Material (stainless steel - type 304)		
F.11.1	Firing mechanism	???????	O.F.
F.11.2	Flow rate control devices		
F.11.2.1	Venturi	???????	O.F.
F.11.2.2	Orifice	???????	O.F.
F.12	Air compressor (capable of constant 100 psi)	2/08/91	R.T.
F.13	Sodium Azide - Copper Oxide fuel	3/07/91	R.T.
F.14	Accumulators (6000 PSI)	2/08/91	D.L.
G.	Testing		L.M.
G.1	Intensifier performance		
G.1.1	HEYPAC with sump		
G.1.1.1	Flow rate	2/22/91	D.G. - L.M.
G.1.1.2	Pressure differential	2/22/91	D.G. - L.M.
G.1.1.3	Charge time from ambient to 1,000 PSI	2/22/91	D.G. - L.M.
G.1.1.4	Charge time from ambient to 2,000 PSI	2/22/91	D.G. - L.M.
G.1.1.5	Charge time from ambient to 3,000 PSI	2/22/91	D.G. - L.M.
G.1.1.6	Charge time from ambient to maximum PSI	2/22/91	D.G. - L.M.
G.1.1.7	Charge time from 1,000 to 3,000 PSI	2/22/91	D.G. - L.M.

G.1.1.8	Charge time from 1,000 to maximum PSI	2/22/91	D.G. - L.M.
G.1.1.9	Hydraulic fluid output temperature	2/22/91	D.G. - L.M.
G.1.2	Without sump		
G.1.2.1	Flow rate	2/29/91	D.G. - L.M.
G.1.2.2	Pressure differential	2/29/91	D.G. - L.M.
G.1.2.3	Charge time from ambient to 1,000 PSI	2/29/91	D.G. - L.M.
G.1.2.4	Charge time from ambient to 2,000 PSI	2/29/91	D.G. - L.M.
G.1.2.5	Charge time from ambient to 3,000 PSI	2/29/91	D.G. - L.M.
G.1.2.6	Charge time from ambient to maximum PSI	2/29/91	D.G. - L.M.
G.1.2.7	Charge time from 1,000 to 3,000 PSI	2/29/91	D.G. - L.M.
G.1.2.8	Charge time from 1,000 to maximum PSI	2/29/91	D.G. - L.M.
G.1.2.9	Hydraulic fluid output temperature	2/29/91	D.G. - L.M.
G.2	Gas from gas generator system		
G.2.1	With venturi	3/07/91	R.T. - D.L.
G.2.2	With orifice	3/07/91	R.T. - D.L.
G.2.3	With flow controller	3/07/91	R.T. - D.L.
G.2.4	Make correction curves/calculations for hot gas	3/07/91	R.T. - D.L.
G.3	Heat exchange of muffler/heat exchanger	3/14/91	L.M. - W.E.
G.4	Evaluate rotating head firing mechanism		
G.4.1	Electric low pressure sensor	3/21/91	D.L. - D.G.
G.5	Fuel cartridges		
G.5.1	Temperature	3/21/91	L.M. - R.T.
G.5.2	Burn rate	3/21/91	L.M. - R.T.
G.5.3	Volume of gas produced	3/21/91	L.M. - R.T.
G.5.4	Gas flow	3/21/91	L.M. - R.T.
G.5.5	Pressure	3/21/91	L.M. - R.T.
G.6	Completed system	4/04/91	ALL
H.	Finalization		W.E.
H.1	Presentation of working prototype		
H.1.1	UCF	4/20/91	W.E.
H.1.2	NASA	4/25/91	W.E.

WHEELCHAIR - GAS GENERATOR SYSTEM
CONSTRUCTION SCHEDULE DEFINITIONS

TASK - DEFINITION

A. Review Requirements

A.1	Review Final Report - review final report from fall-91 semester.
A.2	Review Drawings- review drawings from fall-91 semester.
A.3	Review Calculations

B. Calculations

B.1	Gas volume and burning rate per weight of fuel.
B.2	Flow regulation device size (inlet/exit pressures).
B.2.1	Orifice-calculate size requirements of an orifice.
B.2.2	Venturi-calculate size and shape of a venturi.
B.3	System Volume
B.3.1	Orifice-calculate total volume of system including orifice.
B.3.2	Venturi-calculate total volume of system including venturi.
B.3.3	Flow regulator-calculate total volume of system including regulator.
B.4	Need for an accumulator-calculate pressure residual in gas generator after charging cycle.
B.5	Gas (N_2) pressure produced per weight of fuel
B.6	Firing mechanism spring constant-solve for spring constant K adequate to fire fuel cartridge .
B.7	Muffler/Heat exchanger-calculate exhaust temperature.
B.7.1	Counter flow heat exchange-if exhaust temperature is more than 100 degrees F find amount of counter flow required to bring temperature down to 100 degrees F.
B.8	Corrections for "hot nitrogen" vs. tested "cold air"-testing was done with ambient air, corrections will be required for accurate modeling.

C. Drawings

C.1	Fuel cartridges
C.2	Gas generator body
C.3	Filter
C.4	Flow regulation
C.4.1	Venturi
C.4.2	Orifice
C.5	Transition pieces
C.6	Muffler/Heat exchanger

TABLE 2

WHEELCHAIR - GAS GENERATOR SYSTEM
CONSTRUCTION SCHEDULE DEFINITIONS

D. Reports

D.1 UCF
D.1.1 Work breakdown structures-produce WBS, gantt charts and milestone chart.
D.1.2 Construction and test plan- present test plan and construction details.
D.1.3 Tests
D.1.4 Technical discussion - solid fuel characteristics discussion.
D.1.5 Technical discussion - Hydraulics or case study presentation.
D.2 NASA
D.2.1 Engineering-reports to be presented to NASA.
D.2.1.1 Drawings
D.2.1.2 Calculations-same as calculations defined in section B.
D.2.1.3 Video tape-tape of testing procedures and prototype assembly.
D.2.2 Tests-test reports.

E. Fabrication

E.1 NASA
E.1.1 Firing mechanism-NASA fabrication of the firing mechanism.
E.1.2 Flow regulation devices
E.1.3 Venturi-fabrication of venturi.
E.1.4 Orifice-fabrication of orifice .
E.2 Gas generator system-assembly of gas generation system by UCF.
E.3 Thermocouples (type K)-fabrication of thermocouples(type K).

WHEELCHAIR - GAS GENERATOR SYSTEM
CONSTRUCTION SCHEDULE DEFINITIONS

F. Procurement

F.1 Intensifier
F.1.1 HEYPAC (with sump)
F.1.2 Without sump
F.2 Instrumentation
F.2.1 Hot gas flow meters
F.2.2 Thermocouples-type K thermocouple
F.2.3 Flow meters-pressure regulator, venturi and orifice.
F.2.4 Pressure gauges
F.2.4.1 Static
F.2.4.2 Pressure differential
F.2.5 12 volt supply system
F.2.5.1 Transformer-12 V power supply.
F.2.5.2 Battery-12 V battery alternative for 12 V power supply.
F.3 Hydraulic sump (reservoir)-external sump for hydraulic fluid used by intensifier.
F.4 Hydraulic piping/tubing
F.5 Electric low pressure sensor-proof in principle sensor to prove low pressure will cause firing head to rotate.
F.6 Low pressure servo-servo to rotate firing head upon receiving signal from low pressure switch.
F.7 Stop watch
F.8 Tools-tools required for the assembly and testing of the gas generator system.
F.8.1 Standard and metric sockets
F.8.2 Open end wrenches
F.8.3 Adjustable wrenches
F.8.4 Pliers
F.8.4.1 Needle nose
F.8.4.2 Flat head
F.8.5 Channel locks
F.8.6 Wire cutter
F.8.7 Screwdrivers
F.8.7.1 Phillips head
F.8.7.2 Flat Head
F.8.8 Hammer

F.9 Flow Rate Controller (W.A. Kates Co.)-flow regulator
F.10 Stainless steel tubing (Type 304)-tubing used for plumbing together components.
F.11 Material (stainless steel - type 304)
F.11.1 Firing mechanism
F.11.2 Flow rate control devices
F.11.2.1 Venturi
F.11.2.2 Orifice
F.12 Air compressor (capable of constant 100 psi)
F.13 Sodium Azide - Copper Oxide fuel
F.14 Accumulators (6000 PSI)

G. Testing

G.1 Intensifier performance
G.1.1 HEYPAC with sump
G.1.1.1 Flow rate-CFM input
G.1.1.2 Pressure differential-pressure differential between input and output.
G.1.1.3 Charge time from ambient to 1,000 PSI
G.1.1.4 Charge time from ambient to 2,000 PSI
G.1.1.5 Charge time from ambient to 3,000 PSI
G.1.1.6 Charge time from ambient to maximum PSI
G.1.1.7 Charge time from 1,000 to 3,000 PSI
G.1.1.8 Charge time from 1,000 to maximum PSI
G.1.1.9 Hydraulic fluid output temperature
G.1.2 Without sump
G.1.2.1 Flow rate-CFM input
G.1.2.2 Pressure differential-pressure differential between input and output.
G.1.2.3 Charge time from ambient to 1,000 PSI
G.1.2.4 Charge time from ambient to 2,000 PSI
G.1.2.5 Charge time from ambient to 3,000 PSI
G.1.2.6 Charge time from ambient to maximum PSI
G.1.2.7 Charge time from 1,000 to 3,000 PSI
G.1.2.8 Charge time from 1,000 to maximum PSI
G.1.2.9 Hydraulic fluid output temperature

WHEELCHAIR - GAS GENERATOR SYSTEM
CONSTRUCTION SCHEDULE DEFINITIONS

G.2	Gas from gas generator system
G.2.1	With venturi
G.2.2	With orifice
G.2.3	With flow controller
G.2.4	Make correction curves/calculations for hot gas
G.3	Heat exchange of muffler/heat exchanger
G.4	Evaluate rotating head firing mechanism
G.4.1	Electric low pressure sensor
G.5	Fuel cartridges
G.5.1	Temperature
G.5.2	Burn rate
G.5.3	Volume of gas produced
G.5.4	Gas flow
G.5.5	Pressure
G.6	Completed system

H. Finalization

H.1	Presentation of working prototype
H.1.1	UCF
H.1.2	NASA

WHEELCHAIR - GAS GENERATOR SYSTEM
WORK BREAKDOWN STRUCTURE

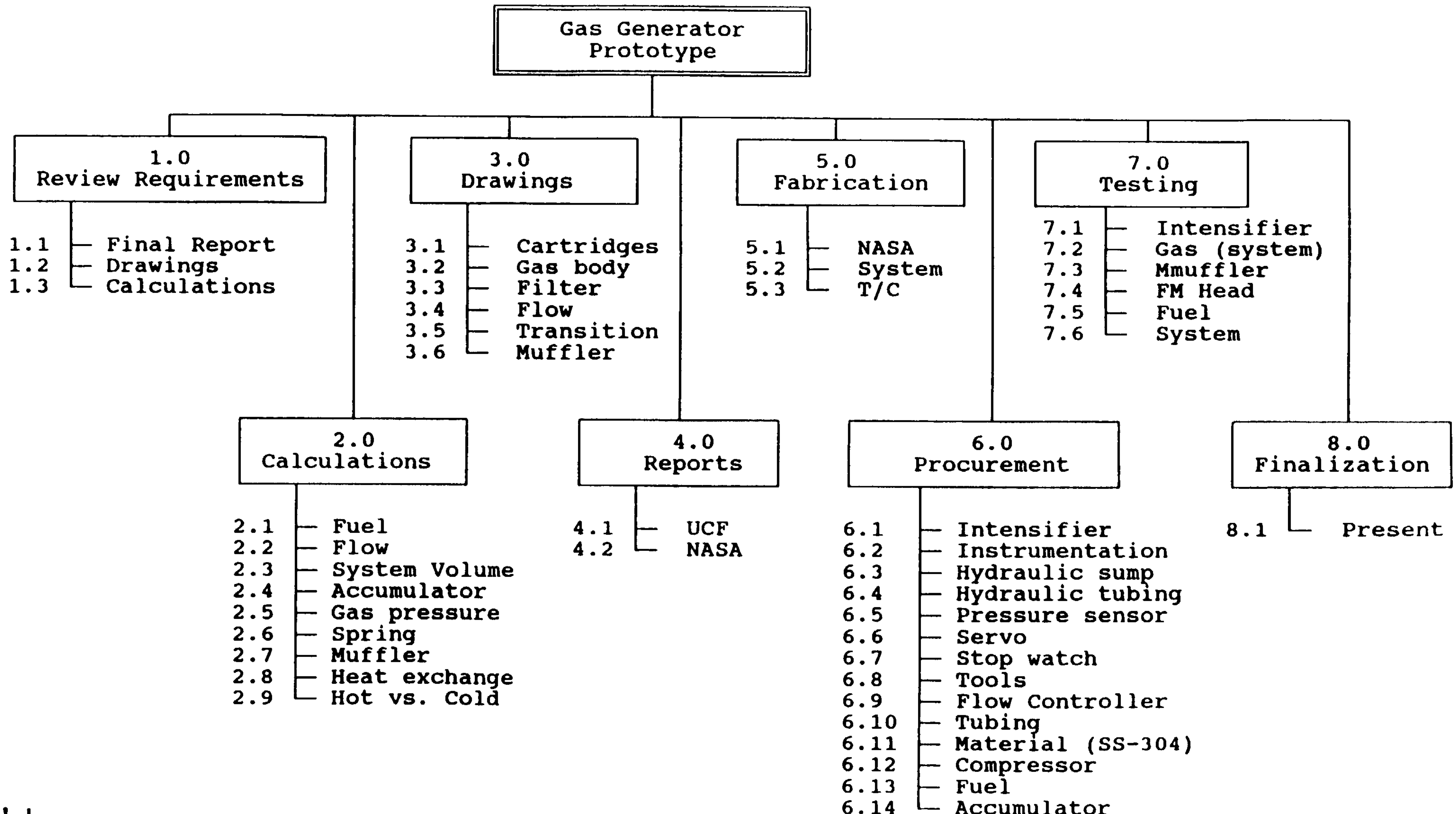

FIGURE 2

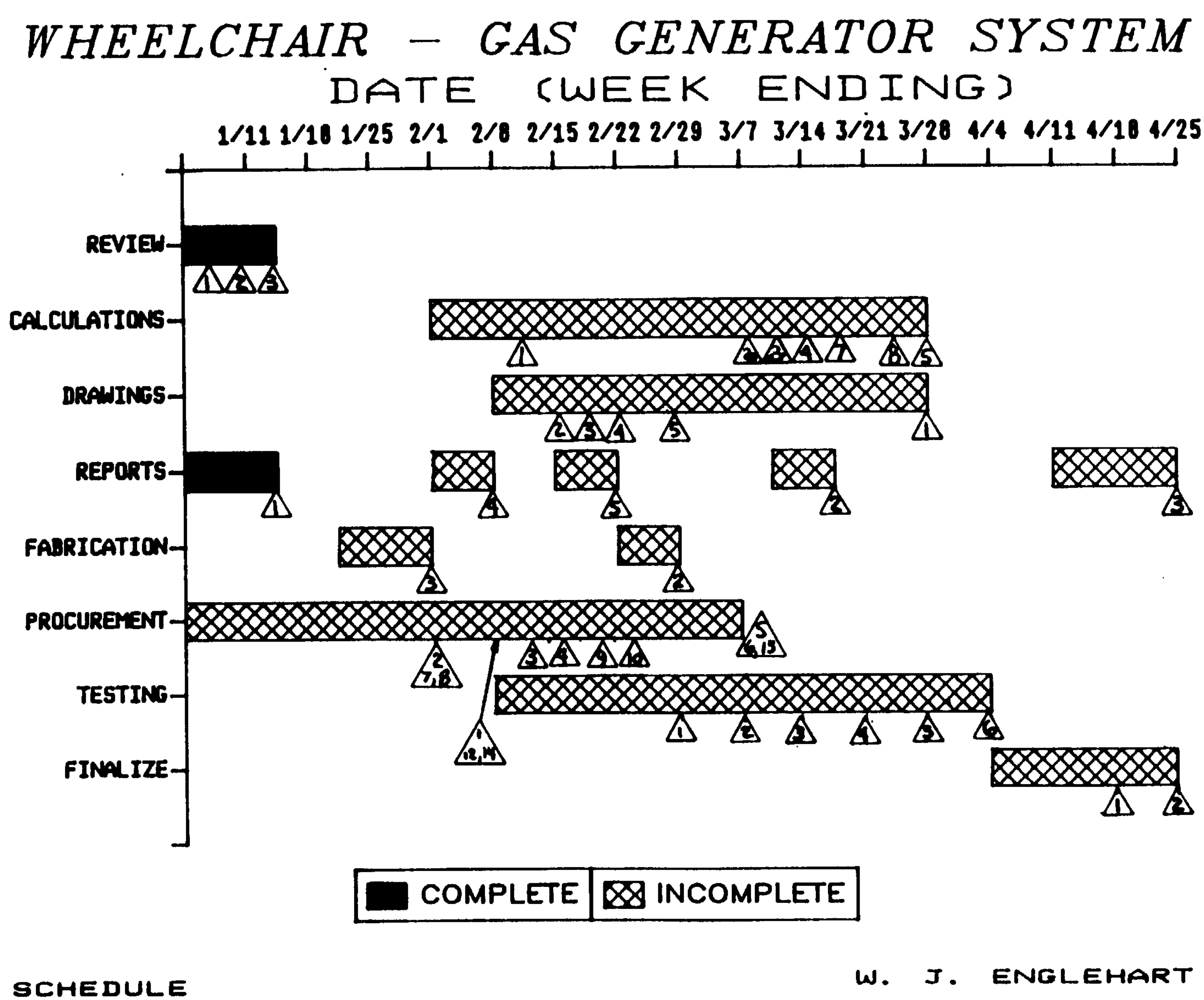
WHEELCHAIR — GAS GENERATOR SYSTEM
DATE (WEEK ENDING)
1/11 1/18 1/25 2/1 2/8 2/15 2/22 2/29 3/7 3/14 3/21 3/28 4/4 4/11 4/18 4/25
REVIEW
CALCULATIONS
DRAWINGS
REPORTS
FABRICATION
PROCUREMENT
TESTING
FINALIZE
COMPLETE
INCOMPLETE
SCHEDULE
W. J. ENGLEHART

FIGURE 4

APPENDIX D

SPECIFYING GOALS REPORT

SPECIFYING GOALS REPORT

WHEELCHAIR - GAS GENERATOR SYSTEM

UNIVERSITY OF CENTRAL FLORIDA
DEPARTMENT OF MECHANICAL ENGINEERING AND AEROSPACE SCIENCES

September 1991

Dr. Loren A. Anderson
EML 4501, Engineering Design

GAS GENERATOR SYSTEM DESIGN TEAM (G^2SDT)

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Michael Scorrano
Duane Grant
David Leblanc

1.0 SCOPE

1.1 Scope. This specification defines the subsystem performance requirements and operational constraints for the Wheelchair - Gas Generator System (GGS) prototype. These subsystem performance requirements and operational constraints have been developed by the Senior Mechanical Engineering and Aerospace Sciences design class at the University of Central Florida in accordance with a report to the Kennedy Space Center, National Aeronautics and Space Administration, "Alternate Power Sources for Wheelchairs" and other applicable documents as described in section 2.0. In the event of conflict, these documents shall take precedence.

1.2 Purpose. The purpose of this document is to formally establish the GGS baseline performance requirements to be used for the design, fabrication and testing of the GGS. This document will be revised to incorporate all approved additional or modified requirements into this baseline.

1.3 Definition. This document provides the performance requirements and operational constraints for the subsystem of the Wheelchair - Alternate Power Source known as the Gas Generator System (GGS) only. The Alternate Power Source system, as a whole, encompasses all hardware associated with the mechanisms that are required to provide power and motion to the wheelchair.

2.0 APPLICABLE DOCUMENTS

2.1 Specifications.

2.1.1 Federal. None

2.1.2 Military. None

2.1.3 NASA. None

2.1.4 Contractor. None

2.2 Standards.

2.2.1 Federal. None

2.2.2 Military. None

2.2.3 NASA. None

2.2.4 Contractor. None

2.3 Drawings. None

2.4 Bulletins. None

2.5 Other Documents.

2.5.1 Manuals. None

2.5.2 Handbooks. None

2.5.3 Industry. American Society of Mechanical Engineers - Boiler and Pressure Vessel Codes for Class II Structures and Piping

2.5.4 Text Books. None

3.0 REQUIREMENTS

3.1 Definition. The information contained in this section pertains to the requirements that must be followed in the design of the GGS. The requirements outlined below will be divided as follows:

3.2.1.1 Firing Mechanism and Solid Fuel Cartridges
3.2.1.2 Gas Generator Body
3.2.1.3 Gas Filter
3.2.1.4 Orifice
3.2.1.5 Transition Piece
3.2.1.6 Intensifer
3.2.1.7 Muffler / Heat Exchanger
3.2.1.8 Gas Generator System

3.2 Performance Requirements.

3.2.1 General Performance Requirements.

3.2.1.1 Firing Mechanism and Solid Fuel Cartridges

3.2.1.1.1 The Firing Mechanisn must ignite all Solid Fuel Cartridge(s). **3.2.1.1.2** The firing head must have the ability to alter its position in order to ignite all Solid Fuel

3.2.1.1.3 The Solid Fuel Cartridge(s) must have the ability to completely burn in a period of time suitable for pressurization of the Accumulator.

3.2.1.1.4 The Solid Fuel Cartridge(s) must be able to pressurize the Hydraulic Accumulator.

3.2.1.1.5 The Solid Fuel Cartridge(s) must be able to be replaced by an inexperienced user.

3.2.1.1.6 The Solid Fuel Cartridge(s) must be available.

3.2.1.2 Gas Generator Body

3.2.1.2.1 The material selected must conform to constraints of availability, weight and cost.

3.2.1.2.2 The material selected must have proper strength.

3.2.1.3 Gas Filter

3.2.1.3.1 The Gas Filter must be able to screen out solids and other contaminants.

3.2.1.3.2 The Gas Filter must be replaceable by the user.

3.2.1.4 Orifice

3.2.1.4.1 The Orifice must be able to reduce the gas pressure.

3.2.1.5 Transition Piece

3.2.1.5.1 The Transition Piece must allow for the smooth transfer of gas.

3.2.1.6 Intensifier

3.2.1.6.1 The Intensifier must provide substantial hydraulic pressure to a level that does not inhibit the system's performance.

3.2.1.7 Muffler / Heat Exchanger

3.2.1.7.1 The Muffler / Heat Exchanger must reduce the temperature and pressure of the system's exhausted gas.

3.2.2 <u>Specific Performance Requirements.</u>

3.2.2.1 Firing Mechanism and Solid Fuel Cartridge(s)

3.2.2.1.1 The Firing Mechanism must ignite the Sold Fuel Cartridge(s).

3.2.2.1.2 The Solid Fuel Cartridge(s) must be able to burn completely within a twenty (20) to fifty (50) second time period.

3.2.2.1.3 The Solid Fuel Cartridge(s) must be sized so they coincide with industrial standards ________________ and ______________________________ .

3.2.2.1.4 The Solid Fuel Cartridge(s) must be able to be removed and installed by an inexperienced user.

3.2.2.1.5 The Solid Fuel Cartridge(s) must be available from at least two independent suppliers.

3.2.2.2 Gas Generator Body

3.2.2.2.1 The Gas Generator Body must be fabricated from a material that conforms to constraints of availability, weight and cost.

3.2.2.2.2 The Gas Generator Body must be designed so that limits of hoop and longitudinal stresses are not exceeded.

3.2.2.3 Gas Filter

3.2.2.3.1 The Gas Filter must eliminate solids and particulate contaminants greater than 100 microns in size.

3.2.2.3.2 The Gas Filter must be easily replaced using common tools.

3.2.2.4 Orifice

3.2.2.4.1 The Orifice must produce an exit pressure of 100 pounds per square inch and maintain a constant flow rate.

3.2.2.5 Transition Piece

3.2.2.5.1 The Transition Piece must not obstruct flow.

3.2.2.6 Intensifier

3.2.2.6.1 The Intensifier must increase an inlet pressure of approximately 100 pounds per square inch to a level of 3000 pounds per square inch.

3.2.2.7 **Muffler/Heat Exchanger**

3.2.2.7.1 The Muffler/Heat Exchanger must be able to decrease the exhausted gas temperature to a level of ambient temperature plus or minus 30 degrees Fahrenheit and ambient pressure.

3.3 Operational Requirements.

3.3.1 General Operational Requirements.

3.3.1.1 Physical

3.3.1.2 Operational Availability

3.3.1.2.1 The GGS must have a high operational availability.

3.3.1.3 Product Assurance

3.3.1.4 Reliability

3.3.1.4.1 The GGS must have a high reliability.

3.3.1.5 Safety

3.3.1.5.1 The Solid Fuel Cartridges must be safe and non-toxic.

3.3.1.6 Environment

3.3.1.6.1 Natural Environment

3.3.1.6.1.1 The GGS shall be designed to operate in natural environment conditions.

3.3.1.6.2 Induced Environment

3.3.1.6.2.1 The GGS shall operate in induced environment conditions.

3.3.1.6.2.1 The GGS Firing Mechanism shall not provide an ignition source in a toxic or flammable gas environment.

3.3.1.7 Maintenance

3.3.1.7.1 The GGS must be easily maintainable.

3.3.2 Specific Operational Requirements.

3.3.2.1 Physical

3.3.2.2 Operational Availability

3.3.2.2.1 The GGS must have an operational availability of at least 98 percent.

3.3.2.3 Product Assurance

3.3.2.4 Reliability

3.3.2.4.1 The GGS must have a reliability of 99.9 percent.

3.3.2.5 Safety

3.3.2.5.1 The Solid Fuel Cartridges must be safe and non-toxic.

3.3.2.6 Environment

3.3.2.6.1 Natural Environment

3.3.2.6.1.1 The GGS shall be designed to operate in natural environment conditions.

3.3.2.6.2 Induced Environment

3.3.2.6.2.1 The GGS shall operate in induced environment conditions.

3.3.2.6.2.1 The GGS Firing Mechanism shall not provide an ignition source in a toxic or flammable gas environment.

3.3.2.7 Maintenance

3.3.2.7.1 The GGS must be easily maintainable by the user with no special tools required.

4.0 VERIFICATIONS

4.1 Definition. The information contained in this section addresses the requirements of the GGS in terms of its individual components. The verifications outlined below will be divided as follows:

4.2.1.1 Firing mechanism and Solid Fuel Cartridge(s)
4.2.1.2 Gas Generation body
4.2.1.3 Gas Filter
4.2.1.4 Orifice
4.2.1.5 Transition piece
4.2.1.6 Intensifier
4.2.1.7 Muffler/exchanger
4.2.1.8 Gas Generator System

4.2 Performance Verifications.

4.2.1 General Performance Verifications.

4.2.1.1 Firing Mechanism and Solid Fuel Cartridge(s)

4.2.1.1.1 Confirm the ignition of the Solid Fuel Cartridge(s) by the Firing Mechanism.

4.2.1.1.2 Verify that the movement of the Firing Mechanism allows for the ignition of each Solid Fuel Cartridge(s).

4.2.1.1.3 Verify the time required to pressurize the hydraulic accumulator.

4.2.1.1.4 Verify the size of the Solid Fuel Cartridge(s) required to pressurize the hydraulic accumulator.

4.2.1.1.5 Confirm that the Solid Fuel Cartridge(s) can be easily removed by an inexperienced user.

4.2.1.1.6 Confirm the availability of obtaining Solid Fuel Cartridge(s).

4.2.1.2 Gas Generator Body

4.2.1.2.1 Verify that the selected materials conform to constraints of availability, weight and cost.

4.2.1.2.2 Verify that the selected materials possess the proper required strengths.

4.2.1.3 Gas Filter

4.2.1.3.1 Confirm the Gas Filter's ability to screen out solids and other contaminants.

4.2.1.3.2 Verify that the Gas Filter can be easily replaced.

4.2.1.4 Orifice

4.2.1.4.1 Verify that the orifice reduces the gas pressure.

4.2.1.5 Transition Piece

4.2.1.5.1 Verify the ability of the Transition Piece to allow for smooth flow.

4.2.1.6 Intensifier

4.2.1.6.1 Verify that the intensifier provides hydraulic pressure.

4.2.1.7 Muffler / Heat Exchanger

4.2.1.7.1 Verify that the pressure and temperature of the Muffler/Heat Exchanger meets design requirements.

4.2.2 Specific Performance Verifications.

4.2.2.1 Firing Mechanism and Solid Fuel Cartridge(s)

4.2.2.1.1 Verify that the ignition of the Solid Fuel Cartridge(s) is performed by visual examination of the remains of the ignited Solid Fuel Cartridge(s).

4.2.2.1.2 Verify that the Solid Fuel Cartridge(s) burns completely within twenty (20) to fifty (50) seconds.

4.2.2.1.3 Confirm that the size of the Solid Fuel Cartridge(s) meets industrial standards.

4.2.2.1.4 Confirm the ease of removing and installing the Solid Fuel Cartridge(s) by an inexperienced user, where an inexperienced user is defined as a person unfamiliar with the system and who has not previously performed this task.

4.2.2.1.5 Confirm with written correspondence, from at least two (2) independent suppliers, that the Solid Fuel Cartridges are available.

4.2.2.2 Gas Generator Body

4.2.2.2.1 Verify that the selected materials are available from at least three (3) suppliers, do not exceed the cost of $100.00 (1991 dollars) per square foot of one inch thick material, and do not exceed 50 pounds per square foot of one inch thick material.

4.2.2.2.2 Verify that all stresses do not exceed their fueled stress with a factor of safety of 2.0 by performing a finite element analysis and providing a finite element model.

4.2.2.3 Gas Filter

4.2.2.3.1 Verify that solids and particulate contaminants greater than 100 microns in size are filtered out.

4.2.2.3.2 Verify that the Gas Filter can be easily replaced utilizing common tools (screwdriver, pliers, etc.).

4.2.2.4 Orifice

4.2.2.4.1 Verify that the orifice produces an exit pressure not exceeding 100 pounds per square inch while maintaining a constant flow rate.

4.2.2.5 Transition Piece

4.2.2.5.1 Verify that the Transition Piece allows for non-obstructed flow.

4.2.2.6 Intensifier

4.2.2.6.1 Verify that the Intensifier produces 3000 pounds per square inch of hydraulic pressure with an inlet pressure of 100 pounds per square inch.

4.2.2.7 Muffler/Heat Exchanger

4.2.2.7.1 Verify that the exhaust gas does not exceed an exit temperature greater than 30 ^{o}F above ambient temperature, and is expelled at atmospheric pressure.

4.3 Operational Verifications.

4.3.1 General Operational Verifications.

4.3.1.1 Physical

4.3.1.2 Operational Availability

4.3.1.2.1 Verify that the GGS must have a high operational availability.

4.3.1.3 Product Assurance

4.3.1.4 Reliability

4.3.1.4.1 Verify that the GGS has a high reliability.

4.3.1.5 Safety

4.3.1.5.1 Verify that the Solid Fuel Cartridges are safe and non-toxic.

4.3.1.6 Environment

4.3.1.6.1 Natural Environment

4.3.1.6.1.1 Verify that the GGS operates in natural environmental conditions.

4.3.1.6.2 Induced Environment

4.3.1.6.2.1 Confirm that the GGS operates in induced environmental conditions.

4.3.1.6.2.2 Verify that the Firing Mechanism does not provide an ignition source in a flammable gas environment.

4.3.1.7 Maintenance

4.3.1.7.1 Verify that the GGS must be easily maintainable.

4.3.2 Specific Operational Verifications.

4.3.2.1 Physical

4.3.2.2 Operational Availability

4.3.2.2.1 Verify that the GGS experiences an operational availability of at least 98 percent.

4.3.2.3 Product Assurance

4.3.2.4 Reliability

4.3.2.4.1 Confirm that the GGS maintains a reliability of 99.9 percent.

4.3.2.5 Safety

4.3.2.5.1 Verify with correpondence from the manufacturer that the Solid Fuel Cartridges are safe and non-toxic.

4.3.2.6 Environment

4.3.2.6.1 Natural Environment

4.3.2.6.1.1 Verify that the GGS operates in natural environmental conditions of one atmosphere at 32 ^{o}F to 105 ^{o}F.

4.3.2.6.2 Induced Environment

4.3.2.6.2.1 Verify that the GGS operates in induced environmental conditions, with pressures ranging from 0 to 2 atmospheres with temperatures from minus 40 ^{o}F to 150 ^{o}F.

4.3.2.6.2.1 Confirm that the GGS Firing Mechanism does not provide an ignition source in a flammable gas environment, by testing the unit in an explosive gas environment.

4.3.2.7 Maintenance

4.3.2.7.1 Verify that the GGS is easily maintainable by the user with no special tools required. Tools required are hammers, screwdrivers, standard and metric sockets and wrenches, adjustable wrenches, pipe wrenches and torque wrenches.

5.0 PACKAGING

6.0 NOTES

APPENDIX E

FLOW RATE CONTROLLER DATA

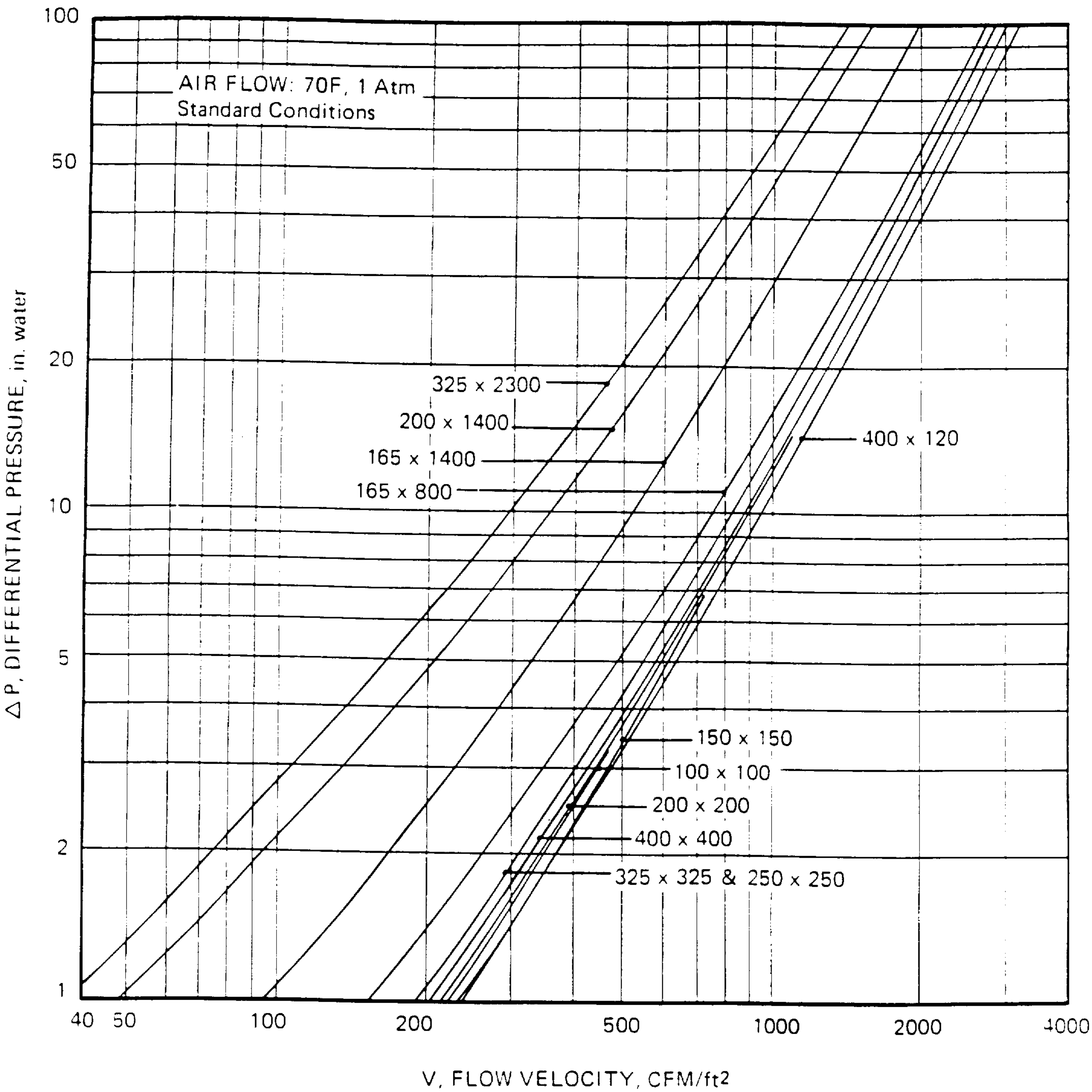
APPENDIX F

FILTER DATA

E-4

Dynapore®

filter plate



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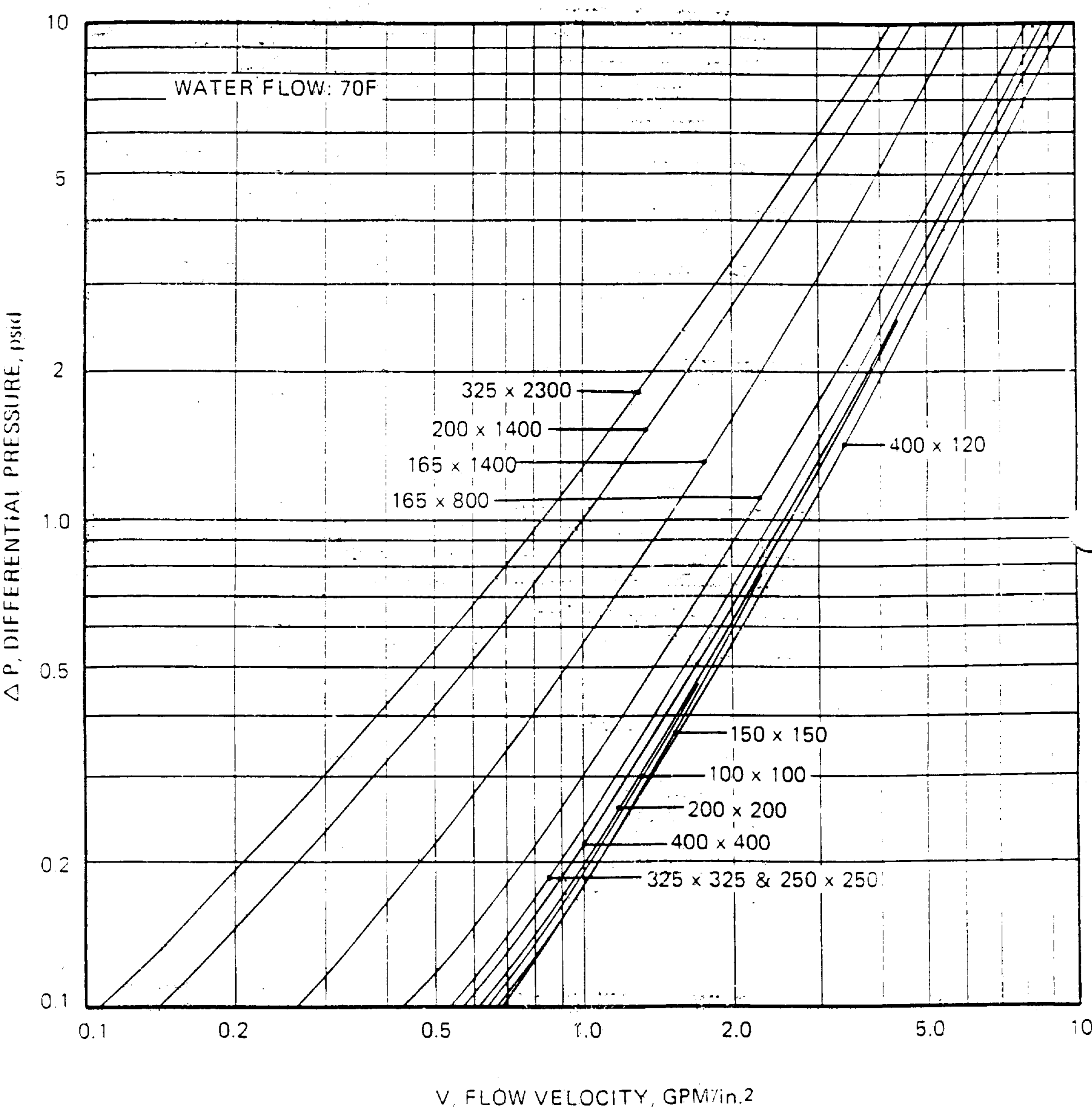

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